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Report on Maintaining Vehicle Fuel Efficiency

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1/ INTRODUCTION

Every vehicle owner, regardless of the number of vehicles involved, must be concerned about rising operating costs. As costs increase, it becomes more difficult to keep them below revenues and the profitability of the operation becomes marginal -- even non-existent in many cases.

The increases in operating costs over the past few years are shown in Figure 1.

This graph represents actual cost per mile data obtained from the top 100 common carriers in the U.S. Although it reflects U.S. prices, these closely parallel costs in Canada and indicate the trends in the various cost elements which make up line-haul operating costs in both countries.

The graph also illustrates the success of efforts by these carriers to hold costs down. For example, although tire prices have been rising, tire cost per mile has remained almost constant as the result of better tires, better driving habits and improved maintenance.

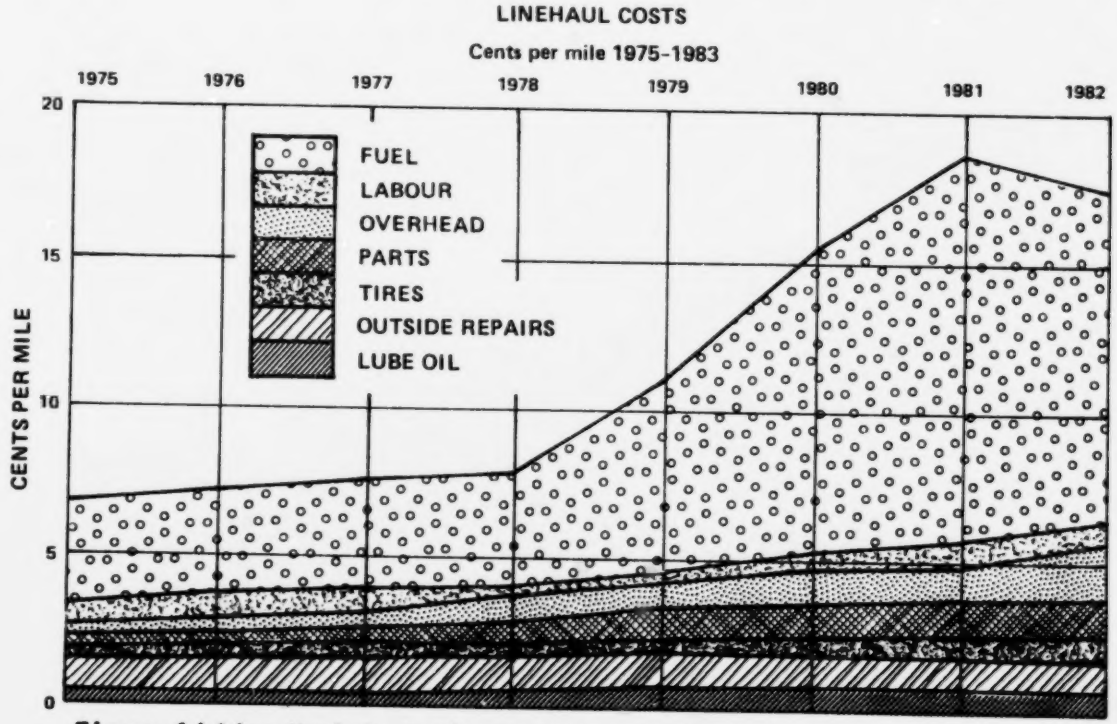


Figure 1/ Line-Haul Costs (cents/mile, 1975-1983) (American data)

Fuel cost per mile was actually reduced in 1982 as the result of fuel conservation efforts, helped by a slight reduction in U.S. fuel prices.

The purpose of this report is to present a number of steps that a fleet owner or owner-operator can take, particularly in the field of maintenance, to minimize fuel costs and other expenses while improving vehicle availability and reliability.

Some of these steps may not, at first glance, appear to be worthwhile because the percentage savings in fuel consumption is small. It is important that these benefits be considered in terms of annual dollar savings in order to appreciate their true value. Moreover, the cumulative effect of a number of small savings can be very substantial.

For example, an action or combination of actions which will reduce the fuel consumption of a line-haul tractor consuming 90 000 L (20 000 gal) of fuel per year by 10% represents an annual savings of 9000 L (2000 gal) per year. At 35¢/L, this amounts to a saving of $3150 per vehicle per year.

Savings in fuel of 10% are not exceptional. Fleets and owner-operators who have taken full advantage of fuel-conserving techniques have obtained savings of 15%, 20% and even 25%.

Many of the steps which can be taken by the maintenance department to keep a vehicle in efficient operating condition not only save fuel but reduce maintenance costs too.

To be fuel efficient, a vehicle must have an engine which burns the fuel efficiently. Such an engine will require less frequent repair and will have a longer life than one that is poorly maintained and inefficient.

A fuel-efficient vehicle must also offer minimum resistance to movement. Power requirements are therefore minimized, and this is reflected both directly in less fuel and indirectly in reduced wear and tear on the drive train and other components such as tires and brakes.

One large Ontario fleet which adopted a 90 km/h speed limit several years ago found that it not only reduced fuel consumption by approximately 10% but for every $1.00 saved in fuel, they saved $0.50 in maintenance costs.

The combined financial benefits resulting from minimizing fuel and parts consumption, frequency of repair, downtime and breakdowns can have a substantial effect on the profitability of a trucking operation.

2/ FUEL CONSUMPTION VS FUEL EFFICIENCY

It is important to understand the difference in the meanings of the terms "Fuel Consumption" and "Fuel Efficiency".

Fuel Consumption is a term which is widely used to describe the vehicle's fuel consumption rate or the average distance travelled while consuming a specific amount of fuel. This is commonly expressed in terms of miles per gallon (mpg). In the metric system fuel consumption rate is the amount of fuel required to travel a specified distance and is expressed in litres per 100 kilometres (L/100 km).

Vehicle fuel consumption is influenced by many factors, including:

- driving techniques and practices;
- utilization by the operations department;
- operating conditions;
- the fuel efficiency of the vehicle; and
- the maintenance of the vehicle.

Vehicle fuel consumption is easily measured by the fleet operator. It requires only the accurate measurement of fuel consumed and distance travelled and then dividing one into the other.

The resulting data is useful for many purposes, but one thing it cannot do is determine the fuel efficiency of a vehicle.

Fuel Efficiency is a measure of the capability of a vehicle to convert the chemical energy in the fuel into mechanical energy which can be used to move the vehicle.

Vehicle fuel efficiency is determined initially by the design of the vehicle, the selection of the components in it and the care with which it is assembled and adjusted. After a vehicle goes into service, its fuel efficiency will be determined by the quality of maintenance. It may remain at its original level, it may deteriorate or it may be raised by means of modifications and substitutions.

There is no easy or simple means of measuring vehicle fuel efficiency. This can only be determined by tests carried out under carefully

controlled conditions. Moreover, the fuel efficiency of a vehicle will vary under different sets of conditions.

For example, engine efficiency is measured in terms of brake specific fuel consumption (BSFC), which is the amount of fuel it consumes to produce one brake horsepower for a period of one hour (lb/hp/h). This is not, however, a single figure because it will change with engine load and RPM as well as with ambient temperature, altitude, humidity, fuel quality, engine temperature, type and grade of oil used, and other factors.

The vehicle owner does not have the time, money and facilities to test an engine while controlling all these variables. He must therefore rely on the maintenance department to ensure that the engine is tuned and adjusted in accordance with the specifications which the manufacturer has determined will produce the highest level of efficiency.

The same approach must be used for other components such as the transmission, drive axle(s) and tires.

If the maintenance department does its job well, the vehicle will be capabable of operating at its highest potential level of fuel efficiency. Utilizing this efficiency to minimize fuel consumption is the responsibility of the driver and the operations department.

3/ THE ROLE OF MANAGEMENT AND SUPERVISION

Top management concern and commitment are essential if a program to conserve fuel and minimize costs is to produce its maximum benefits. Success is not solely the responsibility of the maintenance department but requires the full co-operation and participation of both the drivers and the operations department.

Top management must provide leadership in establishing policies and objectives and must demonstrate on-going commitment to achieving these objectives.

This dedication to achieving results must be transmitted to all who can contribute to success, and particularly to supervisors who are responsible for directing and monitoring those activities which affect fuel economy and operating costs.

Supervisors must, in turn, pass on this commitment to those people who can directly influence fuel consumption -- drivers, mechanics, dispatchers, and others.

Maximum results will only be obtained from the collective efforts of everyone involved from the top of the organization to the bottom.

4/ THE ROLE OF THE DRIVER

It is now widely recognized and accepted that the driver is the most important factor in minimizing fuel consumption. Training in fuel-saving driving techniques and practices is therefore essential and is available from a number of sources, including the Trucksave "Easy Goin" program.

There are fuel consumption measuring devices available which provide the driver with an instantaneous indication of the effects of different driving techniques on fuel consumption. These instruments have proved very effective in training drivers to conserve fuel, in encouraging on-going efforts to minimize fuel consumption, and as a means of monitoring driver performance.

Tachographs are another type of instrument which have proved to be effective for monitoring driver performance and identifying causes of fuel waste.

Driving in a fuel-efficient manner also contributes significantly to extending the life of many vehicle components including engines, clutches, transmissions, brakes and tires. The longer life of these components is reflected in reduced maintenance costs.

While keeping a vehicle in efficient operating condition is usually regarded as the responsibility of the maintenance department, the driver also plays a major part in achieving this objective by recognizing and reporting any symptoms of vehicle malfunctioning.

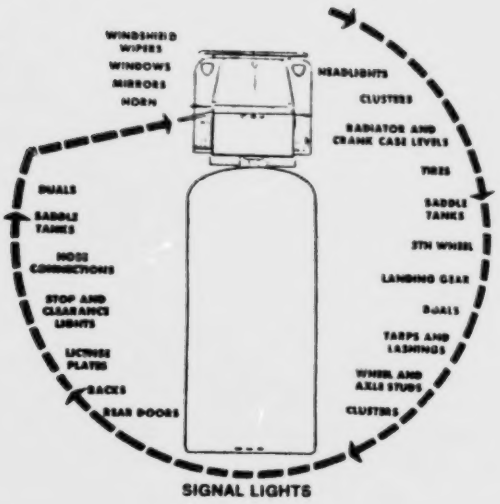
In order to recognize these symptoms, a driver must first be familiar with the characteristics of the vehicle when it is operating normally. This should be part of his training, together with instruction on recognizing various forms of abnormal vehicle operation and on the importance of reporting them without delay.

Recognition of abnormal operations is difficult, if not impossible, for the driver if he is frequently reassigned to vehicles with which he is not familiar. For this reason, drivers should be assigned to the same vehicles to the greatest possible extent. While this may have some

disadvantages, these must be weighed against the potential saving in fuel and maintenance costs.

A driver cannot operate his vehicle in an efficient manner if his instruments are inoperative or inaccurate and if his controls are improperly adjusted. Moreover, he cannot be expected to take a serious interest in saving fuel if the maintenance department is indifferent to the condition of his vehicle. The maintenance department therefore has a responsibility to the drivers to ensure that the vehicles they are operating are in such condition that the drivers can perform efficiently.

The contribution of the driver to maintaining vehicle fuel efficiency starts with performing a brief but thorough inspection of the vehicle at the beginning of his tour of duty. This is usually referred to as a "Pre-Trip Inspection" or "Circle Check" (see Figure 2). When carried out in an organized, systematic manner it takes approximately ten minutes for a single vehicle and fifteen minutes for a tractor-trailer.



Left – This drawing shows a general method of making a systematic circle check before taking out a truck at the beginning of a day's work. Details of the check can, of course, be varied according to the type of vehicle, but generally the principal of making a complete circle should be followed in all cases.

Some of the points to look out for are given in the sample "6-by-6" check below.

Figure 2/ The Circle Check

Defects found during this check which may affect safety or fuel consumption or which, if not corrected, could result in more extensive repairs should be reported immediately.

Once on the road, the driver must remain alert for any indications of vehicle malfunctioning which may result in wasted fuel or damage to the vehicle, and take appropriate action. Both repairs performed en route and defects remaining on arrival at destination must be reported.

All defects should be reported in writing and should be described specifically and clearly so that time and money is not wasted in locating and identifying the faults. An example of a form suitable for reporting vehicle defects is shown in Figure 3.

DRIVER'S DAILY DEFECT REPORT
RAPPORT D'AVARIE
(À REMPLIR CHAQUE JOUR PAR LE CHAUFFEUR)

Department / Service _____ Place / Lieu _____ Date _____ 19__

Vehicle No. / Véhicule Nº _____ Route / Itinéraire _____

Speedometer Reading out / Relevé du compteur au départ _____ in / au retour _____ Mileage / Nbre de milles _____

CHECK ITEMS REQUIRING ATTENTION
INDIQUER L'ORGANE AVARIÉ

Battery / Batterie	☐	Horn / Avertisseur	☐	Springs / Ressorts	☐	Brakes / Freins	☐	Wipers / Essuie-glace	☐
Starter / Démarreur	☐	Clutch / Embrayage	☐	Mirror / Rétroviseur	☐	Steering / Direction	☐	Transmission / Transmission	☐
Engine / Moteur	☐	Tires / Pneus	☐	Body / Carrosserie	☐	Radiator / Radiateur	☐	Radio - Two Way / Poste émetteur-récepteur	☐
Alternator / Alternateur	☐	Windshield / Pare-brise	☐	Locks / Serrures	☐	Cab / Cabine	☐	Other - Specify / Autre (préciser)	☐
Fifth Wheel / Sellette	☐	Tachograph / Tachygraphe	☐	Doors / Portes	☐	Lights / Feux réglementaires	☐		☐

Driver must give details of defect / Renseignements détaillés sur l'avarie _____

_____

_____

_____

_____

Signature of driver / Signature du chauffeur _____

Repairs completed / Réparations effectuées - Date _____ 19__ Time / Heure _____ Signature of Mechanic / Signature du mécanicien _____

Figure 3/ Driver's Daily Defect Report

Source: CN Express

It is equally important that drivers be informed by the maintenance department of any changes or modifications to their vehicles, of their effects on vehicle handling and performance, and of the reasons for making them.

Drivers must understand that modifications made to improve fuel efficiency will not save fuel if the additional available power is used to cruise at higher speeds, accelerate more rapidly or to maintain higher speeds on grades. If these practices cannot be controlled, one or more means of reducing the available power can be utilized.

Every driver must clearly understand that fuel waste and, in some cases, engine damage can result from tampering with engine tune-up settings. This usually takes place in an effort to increase engine power, but tests by one major diesel engine manufacturer showed that a 10% increase in power obtained by increasing the fuel rail pressure resulted in a 15% increase in fuel consumption. Increasing governed RPM to obtain a higher top speed not only increases fuel consumption but can result in major damage and even total loss of the engine.

Most professional drivers, given a clear explanation of the need for conserving fuel and minimizing maintenance costs, and instruction in how they can help, will co-operate in working towards these objectives.

It is important that the drivers' contributions to fuel conservation be recognized by management, supervisors, and by other drivers. Many fleets now post fuel consumption data periodically (usually monthly) and have found that this develops interest and concern which results in better performance.

5/ EFFECTS OF OPERATING CONDITIONS

The fuel consumption of every vehicle, regardless of its potential level of fuel efficiency and how well it is maintained, is affected by changes in operating conditions. Fuel consumption data cannot, therefore, be used to evaluate either the potential level of a vehicle's fuel efficiency or how well it is maintained.

5.1/ Examples of the Effects of Changes in Operating Conditions

Different road surfaces affect fuel consumption. The rolling resistance of a vehicle is approximately twice as great on a packed gravel or dirt road compared to a new smooth concrete or asphalt surface. This can increase fuel consumption by as much as 20%, but the vehicle is no less fuel efficient.

Wind direction and velocity may change not only daily but seasonally so that fuel consumption will also change.

Rain can affect both engine efficiency and rolling resistance, and snow on a road increases rolling resistance.

Ambient temperatures affect both vehicle fuel consumption and fuel efficiency more than any other single factor. In low temperatures engines take longer to reach normal operating temperatures, lubricants offer more resistance, cold tires have more rolling resistance and the load on the vehicle's electrical system is increased. Idling, while often unnecessary, is more widely practised as temperatures drop. This not only wastes fuel but may cause fouled spark plugs or injectors, excessive carbon deposits and other conditions which reduce engine efficiency. Idling at sub-normal engine temperatures greatly increases the rate of cylinder wall and piston ring wear.

Winter weather unfortunately results in a combination of many of these conditions with a cumulative adverse affect on both vehicle fuel efficiency and fuel consumption. Line-haul vehicles are the least affected while vehicles in short-haul and stop-and-go service suffer the most.

6/ THE ROLE OF THE OPERATIONS DEPARTMENT

The objective of the operations department should be to move the maximum amount of revenue traffic at minimum expense. As fuel is the major element in vehicle operating costs, minimizing fuel consumption must be a prime target for operations.

There are many ways in which fuel consumption can be minimized, including the selection of vehicle assignments, routes, schedules and dispatch times, maximizing loads and minimizing empty back-hauls.

The importance of maximizing payloads is underlined by the division of power between moving the vehicle and moving the payload. In the case of a typical 18-wheel tractor-trailer loaded to a gross-combined weight (GCW) of 36 300 kg (80 000 lb), it will take approximately 280 hp to run on the level at a constant 90 km/h. To run empty at a gross combined weight (GCW) of approximately 13 600 kg (30 000 lb) will take approximately 185 hp. Only 95 hp is used to move the payload of 22 700 kg (50 000 lb). Approximately two-thirds of the power required and fuel consumed is therefore used to move the empty vehicle which produces no revenue. This underlines the importance of maximizing both vehicle fuel efficiency and payloads.

Vehicles designed to operate most efficiently at relatively constant highway cruising speeds on level roads cannot perform with the same efficiency on hilly routes, or in short-haul and stop-and-go services. The reverse is also true. It is important, therefore, that operations be aware of the conditions under which each vehicle can perform most efficiently and that this knowledge is used to the best advantage.

When an on-going situation develops where none of the available vehicles can perform the required service efficiently, the maintenance department should be consulted to determine the most cost-effective solution. This may range from the purchase of a new vehicle which has been carefully specified for the required service to modifying an existing vehicle, or to accepting the relatively low efficiency of the vehicle presently performing the service.

Close, continual collaboration between the operations and maintenance departments is essential if the maximum potential fuel efficiency of the vehicles in the fleet is to be realized.

7/ THE ROLE OF THE MAINTENANCE DEPARTMENT

7.1/ Maintenance Department Responsibilities

Maintaining the original fuel efficiency of a fleet of vehicles is only part of the broader role of the Maintenance Department, which includes:

- keeping the vehicles in safe, reliable operating condition at all times;
- improving vehicle fuel efficiency whenever this will be cost-effective;
- minimizing vehicle maintenance costs; and
- co-operating with drivers and operations to eliminate conditions which cause fuel waste and avoidable maintenance expense.

7.2/ Maintenance Department Resources

In order to achieve these objectives, the Maintenance Department must have the necessary resources, which include those outlined below.

7.2.1/ Up-to-Date Maintenance Specifications

Maintenance manuals, parts books, service and parts bulletins covering all vehicles in the fleet are essential. The information in these publications must be readily available to the staff and not buried somewhere in an office. For maximum fuel efficiency, settings, clearances, pressures, etc., must be exact. Mechanics should not be left to rely on their memories, on guessing, or on the say-so of other mechanics; nor should they be using obsolete data or wasting their time looking up information which may be obsolete. Supervisors must ensure that every mechanic has at hand all the specifications he requires to produce the most fuel-efficient and cost-effective vehicle performance possible.

7.2.2/ Knowledgeable Mechanics

New technological improvements, involving all parts of vehicles from air cleaners to tires, are continually being introduced. Mechanics cannot be expected to know how to service, trouble shoot and repair these new components unless they are instructed in their operation and required maintenance.

A wide variety of training courses and seminars are available from the vehicle and component manufacturers, and from their local representatives. Full advantage should be taken of this assistance.

7.2.3/ Spare Parts

An adequate supply of spare parts is essential and must be readily available, either from stock or from outside sources. Reusing parts which are either worn beyond performing efficiently or have been superseded by parts of improved design cannot produce maximum vehicle efficiency.

7.2.4/ Shop Tools and Equipment

To do good work, mechanics must have the appropriate hand tools, instruments and shop equipment. All should be clean, safe and accurate. New technology (e.g., electronic components) requires new tools and instruments. It is impossible to turn out fuel-efficient vehicles without the right equipment.

7.2.5/ Preventive Maintenance Inspection Programs

The foundation of every cost-effective maintenance operation is a series of inspections followed by appropriate and immediate corrective action.

Failure to inspect vehicles thoroughly at regular intervals and to make the necessary adjustments and repairs can result in vehicles remaining in service which are unsafe, unreliable, and inefficient. This, in turn, will be reflected in excessive frequencies of accidents, breakdowns, service disruptions, major repairs and in wasted fuel. All these situations contribute to higher operating costs.

Inspection intervals and procedures must be tailored to different types of vehicles, services and operating conditions. This can only be achieved by continuous analysis of the findings of the inspections and by modifying intervals and procedures as required to minimize overall vehicle costs. This analysis is also essential to provide information to determine whether modifications should be made to present vehicles and for the preparation of specifications for new vehicles.

8/ RECORDS

It is unfortunate that records are too often regarded as useless, a waste of time and an unnecessary expense. On the contrary, good records, properly used, are one of the essential tools for planning, directing and monitoring a trucking company's progress in each area of activity.

Fuel records should account for all fuel purchased as well as consumption by each vehicle. Variances between total fuel purchased and the total issued to vehicles should be identified and the causes corrected (e.g., theft, leakage, short deliveries, inaccurate meters, etc.). Variations in the fuel consumption of each vehicle and between similar vehicles should also be investigated to determine the causes and, where possible, what corrective action should be taken.

Operating records are necessary to identify changes in vehicle operating conditions (loads, routes, schedules, etc.) which affect vehicle fuel consumption and maintenance requirements, as well as to measure the effect of efforts made to improve driver performance.

Maintenance records covering all inspections and all scheduled and non-scheduled repairs are necessary to identify the causes of low fuel efficiency, high frequency of repair, and high maintenance costs.

Other forms of records such as tachograph charts and vehicle fuel recorder tickets can also be valuable in evaluating driver performance and identifying the causes of excessive fuel consumption and maintenance expense.

The information contained in these records is essential for maintaining vehicle fuel efficiency, as well as identifying and correcting other causes of fuel waste. For maximum effectiveness, this information must be accurate and up-to-date. It must also be distributed without delay to those people responsible for taking corrective action, so that the waste is stopped as quickly as possible.

These records may be compiled manually or by computer. Computers are now available at relatively low cost and should be seriously considered by all but the smallest fleets.

9/ THE FUEL EFFICIENCY OF THE VEHICLE

One of the major factors in determining vehicle fuel efficiency is the efficiency with which the energy in the fuel is converted into mechanical energy. Even in the most efficient automotive engines available today, more than half the energy in the fuel is lost inside the engine as the result of imperfect combustion and overcoming internal friction and pumping losses. Most of this wasted energy ends up as heat which goes into the cooling system and out the exhaust pipe. More is lost in driving accessories which are permanently connected to the engine (fan, alternator, air compressor, power steering pump, etc.).

Only the remaining energy in the fuel (less than 30% in the case of a large line-haul diesel) is available to move the vehicle. This is consumed in overcoming friction in the drive train, the rolling resistance of the tires, and the resistance of the air to the vehicle moving through it.

Figure 4 illustrates the distribution of engine power output in a typical tractor-trailer at various speeds.

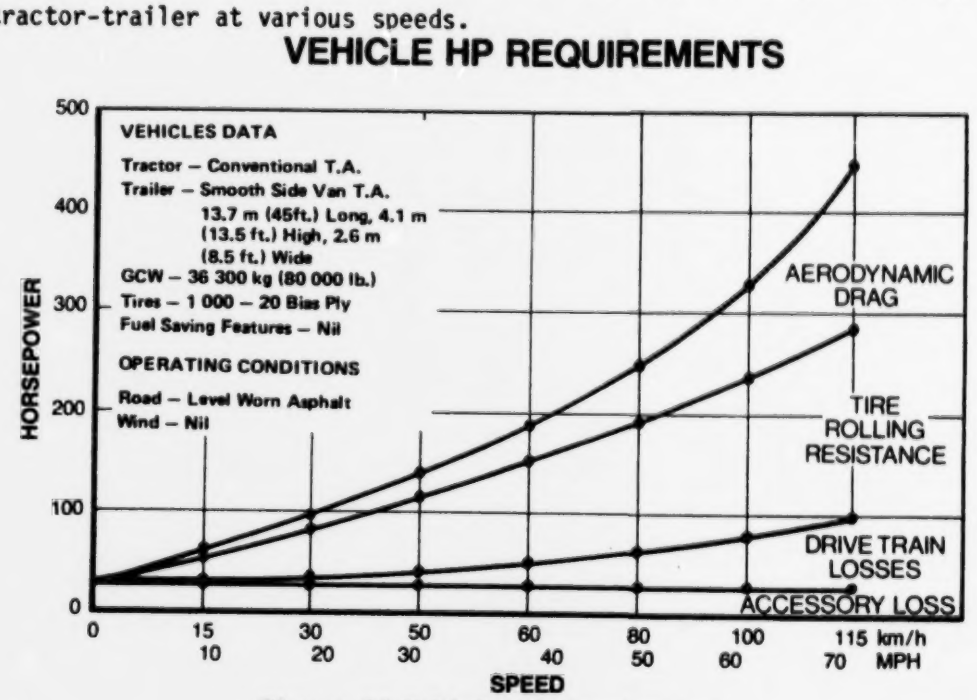


Figure 4/ Vehicle HP Requirements

Source: Cummins Engine Co., Inc.

These power requirements and the energy losses they represent are determined initially by the vehicle manufacturer and the specifications of the purchaser.

After a vehicle goes into service these energy losses may remain at or near their original levels or they may increase, depending on how the vehicle is maintained. They can, in many cases, be decreased by means of modifications or by the substitution of more efficient components and materials such as lubricants.

There are many instances in which the side benefits from improving fuel efficiency are significant. Converting from bias ply to radial tires can reduce the rolling resistance of an 18-wheeler by as much as 30%. This reduces the power required at the wheels, which means less wear on the drive-train. Adding an air deflector can also reduce power requirements and reduce the load on the drive train.

Raising engine temperature by better maintenance and/or modifications to the cooling system controls not only improves engine efficiency but reduces engine wear and improves cab heating. Many other examples could be given.

These side benefits are important because parts costs are rising almost as rapidly as fuel costs. Much of this increase is the direct result of the higher costs of the energy used to produce the raw materials, to manufacture the parts and in packaging, warehousing and distributing them. Much of this energy comes from petroleum.

The objective of the vehicle owner, therefore, should be not only to minimize fuel costs but to keep maintenance costs down by obtaining the maximum life out of every part.

9.1/ Maintaining Vehicle Fuel Efficiency

The fuel efficiency of any vehicle will normally deteriorate as a result of wear, contamination, tampering, abuse and neglect unless steps are taken to prevent or correct these conditions.

Keeping the fuel efficiency of a vehicle up to its potential level is not difficult but requires special attention to the condition of those components and substances (fuels, lubricants, engine coolant, air, and contaminants of various kinds) which have a direct or indirect effect on efficiency.

For the purpose of this report, a vehicle will be considered as consisting of three basic areas or groups of components, which are discussed in the following sections of the report.

The three basic groups are:

- The power plant where the chemical energy in the fuel is converted into mechanical energy.

- The vehicle components which absorb energy to overcome rolling resistance.

- The vehicle components which absorb energy to overcome air resistance.

10/ MAINTAINING POWER PLANT EFFICIENCY

In addition to the engine, the power plant includes the fuel supply system, the air intake and exhaust systems, the cooling system and those accessories which are driven by the engine.

10.1/ Fuels

The amount of chemical energy in the different fuels used in motor vehicles varies according the the type of fuel.

Diesel fuel contains more energy per unit of volume than gasoline. Gasoline contains more than propane.

Regardless of the type of fuel used, the engine must receive an adequate supply of fuel under all operating conditions. Also, the fuel must be free of contaminants which will reduce the efficiency of combustion or damage the engine.

Ensuring that these requirements will be met depends upon the type of fuel.

10.1.1/ Diesel Fuels

The energy in diesel fuel varies according to the grade or blend of grades involved. The heavier grade #2 contains about 7% more energy than grade #1 and is therefore preferred. On the other hand, all diesel fuels contain some wax and #2 diesel contains more than #1. At higher temperatures this wax is dissolved in the fuel and causes no problems. At lower temperatures, however, the wax separates and solidifies into small crystals. When enough crystals are precipitated to form a solid or semi-solid mass, the condition is known as "gelling". Wax crystals, when formed in sufficient volume, will plug the fuel filters and cut off the supply of fuel to the fuel pump.

To counteract this tendency, the oil companies in Ontario blend #1 diesel with #2, in accordance with the lowest anticipated ambient temperatures.

All oil companies do not supply exactly the same blends, but the following is typical.

MINIMUM ANTICIPATED TEMPERATURE	BLEND OF FUEL GRADES
Above -18°C (0°F)	100% #2
-24°C (-11°F)	25% #1, 75% #2
-34°C (-30°F)	50% #1, 50% #2
-40°C (-40°F)	100% #1

The different blends are distributed by the oil companies on a regional basis so that fuel obtained in winter in southern Ontario may be unsuitable for a vehicle headed into a colder area. It should be noted that these blends may be marketed as "#2 grade" although they may contain various proportions of #2 and #1.

For operation in ambient temperatures below -40°C (-40°F), kerosene can be used provided that 1 L of SAE 15W40 or lighter oil is mixed with each 400 L of kerosene (1 qt/100 gal) to supply the necessary lubrication to the fuel pump and injectors.

To minimize the formation of wax crystals, the temperature of the fuel must be kept above its cloud point (the temperature at which the crystals start to form). Fuel filters should be located in warm areas out of the blast of cold ambient air. Fuel heaters may also be required. These are available in many forms and are discussed in Trucksave's Spec'ing Booklet #5, "Fuel-Saving Components and Accessories".

When a fuel heater is used, care must be taken not to raise the fuel temperature above approximately 70°C (160°F) as this will cause oxidation of the fuel and reduced engine efficiency and power. If the fuel line at the pump is too hot to be touched with the bare fingers for more than a few seconds, the fuel is too hot. Fuel heaters should therefore have some provision for cutting off the heat in high ambient temperatures. This may be a thermostat, a manual shut-off or disconnecting the source of heat.

While waxing and fuel filter plugging are restricted to low ambient temperatures, there are two other problems associated with diesel fuel which can affect engine efficiency at any temperature. These are water and solids.

Water is the major problem and may be present in two forms. One is in the form of separate water droplets which settle out in the bottom of storage and vehicle fuel tanks and can be relatively easily pumped out or drained off. Water levels in storage tanks should be checked regularly and pumped out. Water in vehicle fuel tanks should be drained daily, if necessary, depending upon the source of fuel and the amount of condensation. Despite these precautions, some of this water may be picked up by the fuel intake in the tank.

There may also be water in the form of microscopic droplets suspended in the fuel. This moisture will not settle out in the storage or vehicle tanks, but if it reaches the fuel pump and injectors it may may cause serious damage and reduced engine efficiency.

To prevent this, a water separator should be provided in the fuel line. This may be a separate unit or combined with either the fuel heater or filter (see Spec'ing Booklet #5). The sump in the separator must be drained regularly.

The other problem is solids in the fuel. These usually consist, for the most part, of rust particles created by water in the storage and vehicle tanks. While they will be ultimately trapped in the vehicle fuel filters, this can result in frequent and expensive element replacements.

A preferred method is to install a large filter with a sump on the fuel dispenser. This will collect both free water and solids pumped out of the storage tank, it is easily serviced, and it reduces both vehicle maintenance costs and the possibility of fuel starvation while a vehicle is in service.

10.1.2/ Gasoline

In the case of gasoline, there is no significant difference in the energy content of different types and grades. Unleaded fuel must be used if specified by the engine manufacturer to prevent damage to the engine and its emission control system. No increase in fuel efficiency will be

obtained by using premium unleaded gasoline if the engine will operate normally on regular grade. The choice of fuels should be based on engine octane requirement.

Minor adjustments may be required to the ignition timing to eliminate detonation, but these adjustments should not exceed the limits set down by the engine manufacturer. If these limits must be exceeded to stop the detonation, the engine will not perform efficiently and the cause should be identified and corrected.

The main problem associated with gasoline is water contamination, caused primarily by condensation in the fuel tanks, which can result in engine misfiring, frozen fuel lines and corroded tanks.

Water resulting from condensation can be minimized by keeping both storage and vehicle tanks as near the full level as practical and by removing accumulated water from storage tanks periodically. Most modern gasolines contain an additive which will absorb water, making the use of "gas-line antifreeze" unnecessary. If frozen fuel lines are a problem, the cause is probably an outside source -- missing vehicle or storage tank caps; water getting into underground tanks during filling; failure to keep the water level in the storage tanks down to the minimum level, etc.

Another factor to consider with gasoline is vapour pressure, which is the tendency of the fuel to evaporate or vaporize at a specified temperature. As ambient temperatures drop, the tendency of a particular gasoline to vaporize decreases, resulting in hard starting and rough, inefficient engine operation during the warm-up period.

To offset this situation, fuel suppliers alter the composition of all gasolines, leaded and unleaded, to raise the vapour pressure during periods of low ambient temperatures. This does not significantly affect the energy content of the fuels but may create operating problems which affect both engine performance and efficiency.

This situation can develop when a vehicle has been refuelled with low vapour pressure gasoline in a mild area such as southwestern Ontario and

travels into a much colder area. The reverse situation can also arise when a vehicle which has been fuelled with high vapour pressure or "winter grade" gasoline encounters much higher ambient temperatures. Under these conditions, the fuel may vaporize excessively causing vapour lock, carburetor boiling and flooding.

10.1.3/ Propane

Propane used in cars and trucks must conform to specification HD-5. Commercial grade propane which is used for heating and industrial purposes is not only less fuel efficient but may contain impurities which can seriously damage an engine.

Propane contamination is rarely encountered because the fuel is stored out of contact with ambient air and other possible sources of contaminants. If the operation or efficiency of an engine appears to be adversely affected by some condition in the fuel, the problem should be brought to the attention of the propane supplier.

10.1.4/ Fuel Records

Accurate fuel records are essential in order to monitor both fuel utilization and costs.

These records should cover all fuel purchased and delivered to the fleet's storage tanks as well as all fuel dispensed to vehicles. With present high fuel prices, no vehicle operator can afford to neglect the close control of all fuel purchased. Some of the possible causes of fuel losses and waste include:

- short deliveries;
- excessive water content;
- leakage;
- spillage;
- inefficient driving techniques;
- unnecessary idling;
- inefficient vehicle assignments;
- poor maintenance; and
- theft.

Complete and accurate fuel records can provide valuable information for use in identifying these and other situations.

10.2/ The Engine

Engine manufacturers are continually improving the efficiency of their products, while at the same time meeting increasingly restrictive limits on exhaust emissions and noise.

The fuel efficiency of some line-haul diesels has been increased by as much as 20% over the past several years. Parallel improvements have been taking place in other diesels and in gasoline engines.

These increases in efficiency have been achieved by the collective effect of many refinements in engine design combined with changes to external parts such as air intake and exhaust systems which allow engines to breathe more freely, by closer control of engine temperatures, and other measures.

Nevertheless, even in the most efficient turbocharged diesel engines being marketed today, less than 40% of the energy in the fuel is converted into mechanical energy that turns the crankshaft. The rest of the energy is lost and ends up as heat transferred to the cooling system and going out the exhaust. In gasoline and propane engines, the percentage of usable energy is substantially less than 40% -- usually it is in the 15% to 25% range.

10.2.1/ Engine Tune-Up

Manufacturers have devoted a great deal of research to determine the most fuel-efficient tune-up specifications for their engines. Even minor variations from these recommendations can have a significant effect on fuel efficiency as well as affecting power and engine life. Moreover, the continuing search for improved fuel economy results in these specifications (which may also involve parts substitutions) being changed from time to time.

For maximum fuel efficiency, the latest tune-up specifications must be followed exactly. Above all, tampering with settings by drivers must not be tolerated. This may achieve the usual objectives of more power and/or rpm but inevitably wastes fuel and may result in damage to the engine.

10.2.2/ Air Intake Systems

Both the design and maintenance of the engine air intake system can affect fuel efficency, particularly in the case of engines which operate at high speeds and loads.

Diesel engines consume approximately 8000 L of air to burn 1 L of fuel. These engines have no throttles to reduce the volume of intake air at light loads and when idling. For this reason, the volume of air passing through the air filters is more closely related to total engine revs than to power developed. In the case of gasoline and propane engines with throttles to control the air flow, the volume of air consumed is more related to power, and as these engines are seldom operated at full throttle, the volume of air passing through the filters is much less.

Because line-haul diesels operate in their upper power and rpm ranges most of the time, any excessive air intake restriction will significantly reduce both their fuel efficiency and maximum power as shown in Figure 5.

A well-designed intake system with a new filter element should create a restriction of not more than 8 to 10" of water (H_2O).

If the restriction is greater, either the intake ducting or the filter (or both) may be the cause, and larger ducting or a larger filter may be the solution. Tests of the effect of restriction on fuel consumption have shown that reducing the restriction from 25" H_2O to 5" H_2O resulted in fuel savings of approximately 1.3%. Other tests to determine the effect of restriction on maximum power showed a loss in power of 3.4% when the restriction was increased from 5" H_2O to 25". Obviously, less restriction is better.

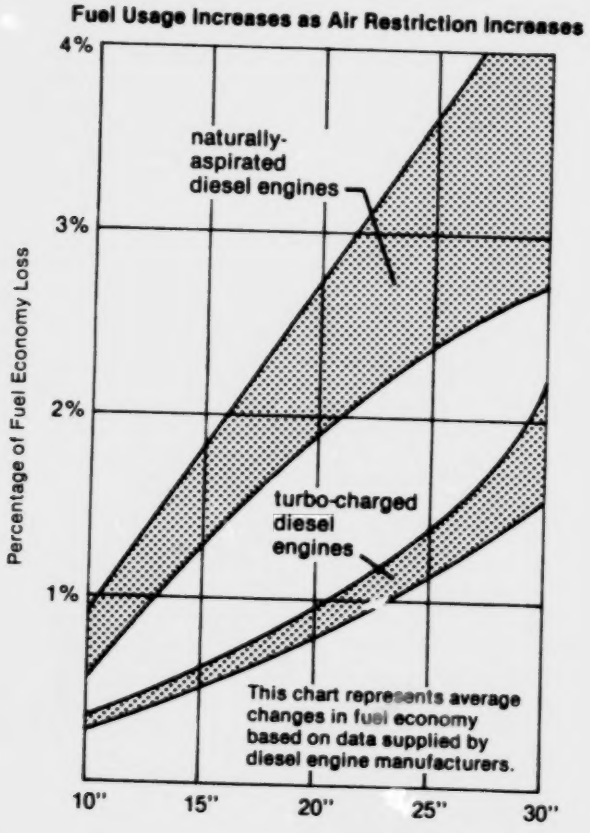


Figure 5/ Effect of Air Restriction on Fuel Economy
Source: Donaldson Co. Inc.

Large off-road diesels which operate at high loads and rpm are similarly affected by excessive restriction in the air intake system and should meet the same standards. In these cases, larger filters may be necessary to keep the frequency of servicing down to a reasonable level.

Mid-range and small diesels, in most cases, operate at well below their maximum power and rpm but nevertheless consume much greater volumes of air than their gasoline-powered counterparts. In many vehicles, however, the intake systems do not have the necessary increased filter capacity, and if they cannot be suitably modified, more frequent servicing is the only answer.

It is important to know whether excessive restriction is increasing fuel consumption or reducing power. This can be determined by means of a restriction gauge, which should measure the total restriction of the air intake system and should therefore have its sensing connection located as close to the engine intake as possible (turbocharger inlet or manifold intake). In this position, it will measure the combined restriction of the ductwork and the filter.

Restriction gauges are recommended for all large and mid-range diesels. The dash-mounted type, which registers the maximum restriction, is preferred (See Figure 6). These gauges can be conveniently checked at any time by a driver or mechanic, whereas the instantaneous-registering type requires continuous watching by the driver.

Figure 6/ Air Intake Restriction Gauge

A restriction gauge of this type costs $30 to $40 and will quickly pay for itself through a combination of fuel savings and elimination of premature filter replacement.

It is further recommended that, for maximum fuel efficiency, the filters be replaced when the intake restriction reaches 20" H_2O for turbocharged engines and 15" H_2O for naturally-aspirated engines.

In the case of gasoline and small diesel engines, air filter elements should be changed at the intervals recommended by the vehicle manufacturer, taking into account exceptional conditions, such as dusty off-road operations, which may require more frequent replacement.

10.2.3/ Exhaust System

Exhaust back-pressure is a factor in determining fuel efficiency only when an engine is operating at, or near, full power and rpm -- that is, when the volume of exhaust gas is greatest. For this reason, excessive back-pressure is unlikely to be encountered anywhere but in line-haul operations. It can occur, however, in any vehicle if a loose baffle blocks the muffler or the exhaust pipe is pinched. These defects should be corrected as part of any normal maintenance program.

In the case of line-haul diesels, piping may have been modified or substandard replacement mufflers installed, creating excessive back-pressure.

Exhaust back-pressure is measured in inches of mercury (" Hg). Most standard exhaust systems on line-haul diesels have a back-pressure of 4" Hg or less. For maximum fuel efficiency, the lower the pressure the better (as illustrated in Figure 7).

In the case of turbocharged diesels, each reduction of 1" Hg in pressure will reduce fuel consumption by approximately 0.5% (1% in the case of naturally-aspirated engines). Reducing the back-pressure to 1" Hg or less can therefore produce a significant increase in fuel efficiency.

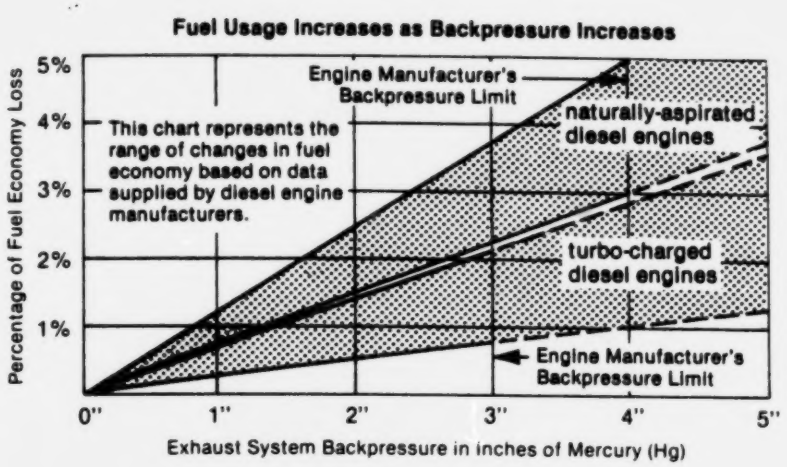


Figure 7/ Effect of Back-Pressure on Fuel Economy
SOURCE: Donaldson Co. Inc.

This can be achieved by using correct pipe sizes, minimizing the number of elbows and bends, and by using low back-pressure mufflers which still meet noise limit standards.

Low back-pressure mufflers for large diesels are available from a number of manufacturers at a cost of $50 to $75 more than standard mufflers.

Equipment and techniques for measuring back-pressure are expensive and complex and not suitable for fleet use. If you suspect that you may be wasting fuel because of excessive back-pressure, request one of the major muffler manufacturers to survey your line-haul tractors. They will recommend the most efficient piping and mufflers for each of your vehicles.

10.2.4/ Cooling System

Every engine manufacturer has determined the temperatures at which their engines operate most efficiently. Many also indicate a range of temperatures, above and below, at which both fuel efficiency and engine wear are adversely affected, as indicated in Figure 8.

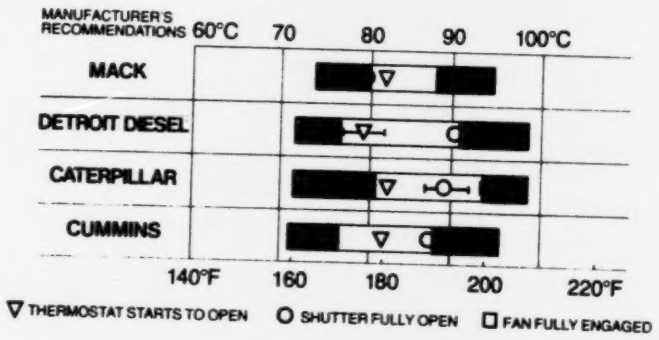


Figure 8/ Manufacturers' Recommended Engine Temperatures

Practically all engines, regardless of the type of fuel used, operate most efficiently in the 80 to 90°C range (175-195°F). Tests on the effect of engine temperature on line-haul diesel engines have shown that increasing engine temperature produced significant fuel savings. These savings averaged approximately 1% for each 5°C (9°F) the temperature was raised.

Raising engine temperature also substantially reduces engine wear. Tests reported by the Society of Automotive Engineers (SAE) showed that the rate of cylinder wall wear at 38°C (100°F) was approximately eight times as great as at 82°C (180°F). Other tests showed that increasing engine temperature from 66°C (150°F) to 86°C (185°F) reduced cylinder wall and ring wear by approximately 30%.

As engine temperature is normally judged by both drivers and mechanics by means of the instrument panel gauge in the vehicle, this gauge must be accurate, particularly in the 80 to 100°C (175-200°F) range. Permissible error is ±3°C (±5°F).

Temperature gauges, particularly the electric type, are notoriously unreliable and can mislead observers into believing that an engine is either hotter or colder than it actually is.

The first step in checking the operation of the engine temperature controls is therefore to check the accuracy of the gauge. This should be done with a high quality master gauge or by using a hot water heater and an accurate thermometer.

If replacement of the sending unit or complete gauge assembly is necessary, the replacement should be similarly checked before installation.

In the case of electrical gauges it is important that the sending unit be grounded properly, as any additional resistance will affect the gauge reading.

If a vehicle is fitted with only an overheating indicator light, it is impossible to determine if the engine is operating at the proper tempera-

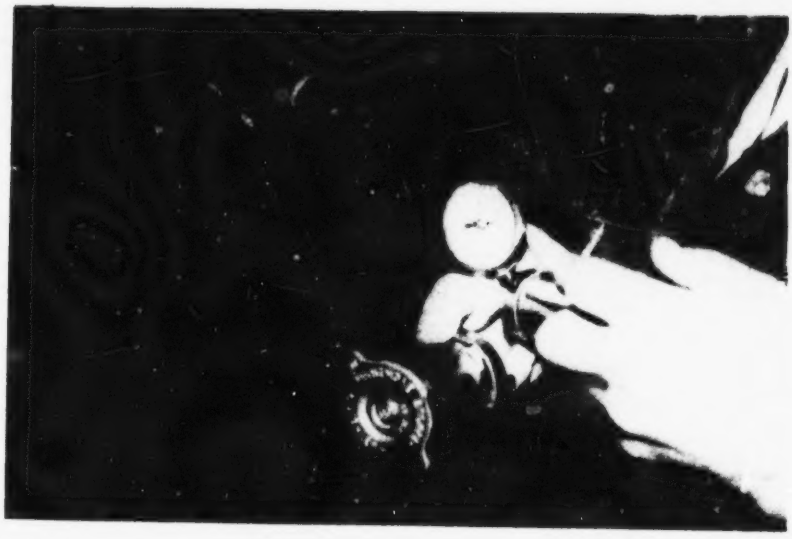


Figure 9/ Radiator Cap Tester

This tool costs approximately $115 complete with adaptors to fit most radiator caps and can also be used to test coolant systems for leakage. Permissible error in the pressure release point of the radiator cap is ±1 psi.

Both thermostats and rad caps are inexpensive but critical in maintaining fuel efficiency and minimizing engine maintenance costs. The savings in fuel and longer engine life far outweigh the cost of maintaining these components in first class condition.

The fluid used in the cooling system is an integral part of the design of the system. Most engine manufacturers recommend the year-round use of a 50/50 water-ethylene glycol mixture which has a higher boiling point than water and therefore permits the engine to operate at a higher, more efficient temperature.

While plain water boils at 100°C (212°F) at atmospheric pressure, a 50/50 glycol solution boils at approximately 110°C (230°F). This boiling point is raised 1.4°C (2.5°F) for each pound of pressure increase, so that a 50/50 glycol mixture in a cooling system pressurized to 10 psi will boil at approximately 124°C (255°F).

The higher boiling point of pressurized glycol mixtures minimizes the risk of boiling at local hot-spots such as around the exhaust valve seats, which can result in extensive engine damage. This is most likely to occur if the engine has been working hard and is at maximum operating temperature and is then shut-down without a 3-5 min cool-down period.

The cleanliness of the cooling system has a direct effect on both engine efficiency and engine life.

The temperature gauge indicates only the temperature at one particular point in the cooling system. When the cooling system is in "as new" condition, the gauge is an acceptable indicator of the temperature of the engine in general, but as scale and sludge accumulate and normal coolant circulation is disrupted, both hot and cold areas develop, engine efficiency drops and the probability of serious engine damage increases.

To minimize deterioration of the cooling system, corrosion inhibitors must be used, either as a component of the antifreeze or in the form of additives. With the increasing use of aluminum, which is sensitive to alkaline solutions, care must be taken to select inhibitors which will not attack any of the metals in the cooling system. Many vehicle owners, in an effort to minimize maintenance costs, leave antifreeze in cooling systems for extended periods, with or without using additives and with hose replacements and flushing performed only when absolutely necessary. This practice is not recommended. Not only will engine efficiency be reduced, but engine life will be shortened and premature complete engine loss is highly possible. Moreover, there is the likelihood of radiator perforation, plugged radiator and cab heater cores and a wide variety of unscheduled repairs which, combined with reduced fuel efficiency, will cost much more than a systematic overhaul of the cooling system at regular intervals.

For maximum fuel efficiency and engine life and for minimum long-term cost, the following procedure is recommended as a general guideline. The instructions from the manufacturers of the vehicle, engine, flushing compound and antifreeze should be followed where applicable.

Go over the entire cooling system once a year, preferably in the fall. At this time:

- Pressure test the system for leaks and correct as necessary.
- Flush the cooling system thoroughly (engine, radiator and cab heater circuits) with approved flushing compound and neutralizer. Flush with clear water thoroughly to remove all traces of neutralizer.
- Replace any rubber hoses with silicone hoses, using double worm screw type clamps (silicone hoses do not bond to metal fittings like rubber hoses and therefore have a greater tendency to leak).
- Check the thermostat for make, model and opening temperature. Replace if it is not to engine manufacturer's latest specification. If the present thermostat is the correct make and model, check opening temperature before replacing.
- Check the overheating alarm (install an alarm, if not already fitted, in all large and mid-range diesels and in H.D. gasoline engines).
- Check the temperature gauge for accuracy -- replace if necessary.
- Check the shutters, if fitted, for shutterstat setting, shutter operation and tightness of shutters when closed.
- Refill the cooling system with a 50/50 mixture of a reputable brand of ethylene glycol antifreeze and water.
- Test the rad cap pressure setting -- replace if necessary.
- Run the engine up to shutter opening temperature, bleed any air from the system, top-up as required and check thoroughly for leaks. Retighten all hose clamps.

Radiator shutters are essential to maintain efficient operating temperatures in diesel engines operating in low ambient temperatures.

In these temperatures, no matter how well the thermostat is functioning, it cannot maintain the engine at optimum temperature under all conditions. The shutters keep cold air (either ram-air or fan-propelled) off the exterior of the engine, this shortens warm-up time and reduces heat loss at idle and under light loads. They also assist in maintaining engine temperature in the desired range, which is higher than the thermostat opening temperature.

Tests on line-haul diesels have shown that with 82°C (180°F) thermostats, fuel consumption was reduced approximately 3.5% by installing shutters which opened at 90°C (195°F).

Not only do shutters increase engine efficiency and reduce fuel consumption, but the faster warm-up and higher coolant temperatures improve cab heating and defrosting.

Radiator shutters are recommended for all large and mid-range diesels. The cost, complete with controls (air or vacuum), will range from $300 to $400, plus installation.

Shutters, to be effective, must be properly maintained. This involves a clean air supply (filters must be serviced regularly); correct shutterstat setting; correct linkage adjustment; periodic lubrication and good physical condition.

When in good condition, the shutters will open and close freely (lubricate vane pivots regularly with shutterstat fluid, a solvent-lubricant or with light oil). When closed, the shutter vanes should be air-tight. This can be checked with a trouble light (no light should show between the vanes) or by using a sheet of paper (with the fan operating there should not be enough suction between the vanes to hold the paper against the front of the shutters). Very little air leakage is required to destroy the potential benefits which shutters can provide.

Radiator shutters are seldom required for gasoline engines. The lower thermal efficiency of these engines results in a surplus of heat going into the cooling system. If an engine is operating below the manufacturer's recommended temperature, check the make, model and opening temperature of the thermostat.

The primary function of the fan is to prevent overheating. Temperature-controlled fans have the added advantages of saving fuel by operating only when needed and reducing vehicle noise when they are not operating. In low ambient temperatures, they also eliminate the forced circulation of cold air over the exterior of the engine, resulting in faster engine warm up and higher operating temperature. This, in turn, saves fuel and reduces engine wear (see also "Engine-Driven Accessories", below).

Winter fronts are not necessary as a means of maintaining engine temperature if the thermostat and shutters are functioning properly, and if the frontal area, except for the radiator, is completely closed to prevent cold ram air from reaching the engine. Failure to open a winter front in milder weather can cause engine overheating and serious damage. For this reason, they should never be used without an engine overheating alarm. On the other hand, a winter front may be necessary on COE cabs which are poorly insulated in order to maintain adequate cab temperature.

Regardless of the reason for using a winter front, the area in front of the fan should be either fully closed or fully open. If a portion of this area is covered it creates an uneven flow of air to the fan, which causes blade flexing and vibration which can result in blade failure and damage to the hub or water pump bearings.

Most winter fronts are either installed by drivers or by the maintenance department at the request of drivers. The reasons usually given are that either the engine is running cold, or the cab is cold.

If the reason given is that the engine is running cold, the cooling system controls should be checked out as previously outlined. If the driver still complains of being cold, the cab heater should be checked for proper operation and the cab should be checked for air leaks

resulting from unplugged holes, missing grommets, door seals and ventilator gaskets, lack of insulation and any other possible cause of heat loss.

When checking the cab heater, check coolant circulation (air lock or plugged core), air circulation (dust, etc. in core air passages), and fan operation.

10.2.5/ Engine Friction and Pumping Losses

The amount of power consumed in overcoming engine friction and pumping losses varies in proportion to the engine rpm (see Figure 10).

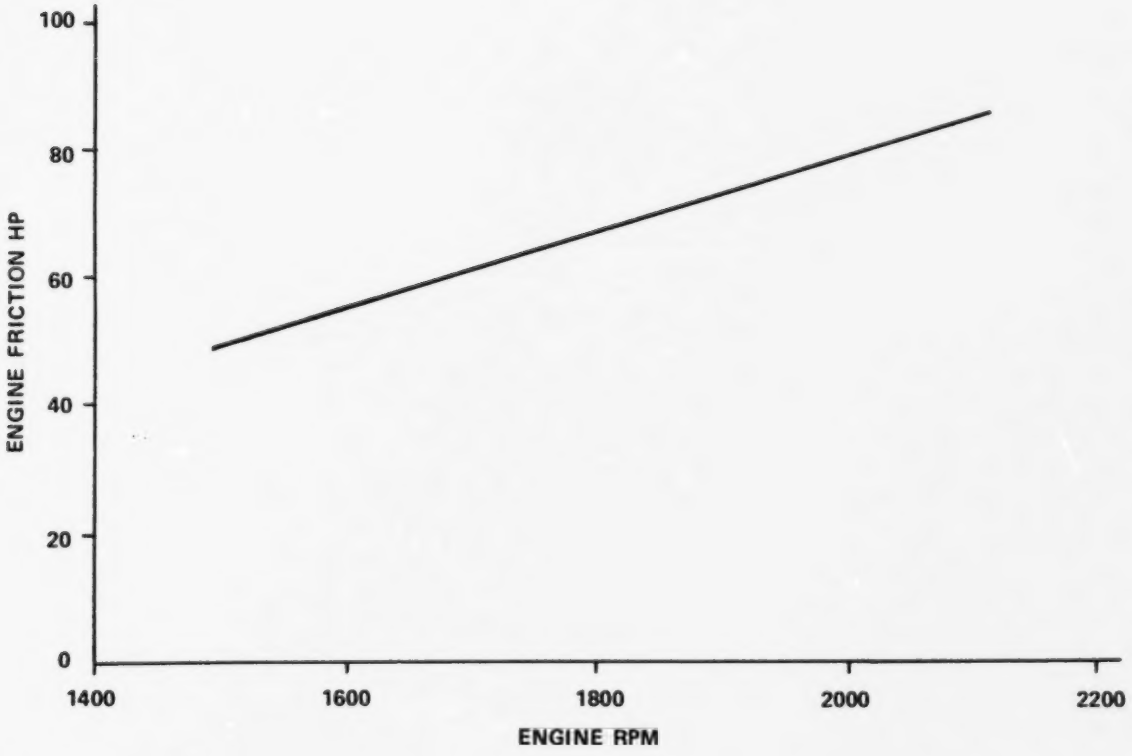


Figure 10/ Engine Friction HP vs RPM -- Typical Line-Haul Diesel Engine
Source: Caterpillar Tractor Co.

Tests carried out on one typical line-haul diesel engine showed that the power consumed by the engine was approximately 55 hp at 1600 rpm and more than 90 hp at 2100 rpm. This is one reason for the higher fuel efficiency of low rpm engines and why engines, regardless of fuel type and size, should be operated at the lowest rpm which will produce the required torque and road speed.

Driving technique is, therefore, a major factor in minimizing the amount of fuel used to overcome internal engine power losses. These techniques and practices include:

- short warm-up periods;
- progressive shifting;
- cruising at minimum rpm;
- minimum idling; and
- short cool-down periods.

These subjects are covered in detail in the Trucksave "Easy Goin" program. All these techniques also contribute to reduced engine wear and lower maintenance costs.

The other significant factor in minimizing engine friction losses is the choice of engine crankcase oil. This involves the type of oil (petroleum base, partial-synthetic base or all-synthetic base), the SAE grade (15W40, 10W30, etc.) and the API classification (CC/SE, CD/SE, CD/SF, etc.). Consideration must also be given to the type of service in which the vehicle is used and to the ambient temperatures which will be encountered.

Conventional petroleum-based oils are the least expensive and are available in SAE grades suitable for use (including starting) at ambient temperatures down to -35°C (-30°F). Partial-synthetic oils (blends of petroleum and synthetic base oils) are suitable for use in ambient temperatures as low as -45°C (-50°F) but cost approximately 25% more than conventional oils.

All-synthetic base oils are also available from some companies. Tests have shown that these oils, which have a very high level of lubricity, can produce significant fuel savings, but these must be weighed against the high cost of this type of oil which is approximately 300% more than that of petroleum-base oils.

15W40 petroleum-base oil is widely used in many parts of Canada and the U.S. as an all-season oil for line-haul diesels. This oil is not recommended for engines which must be restarted when the oil temperature is below approximately -25°C (-15°F). At these lower temperatures, this oil is too thick to flow easily, creating extra cranking resistance and poor lubrication during cranking and initial start up. For these reasons, an oil pan heater should be used to keep the oil warm enough to flow easily (see Spec'ing Booklet #5).

SAE 0W30 oils have recently appeared on the market and, at first glance, appear to be the answer to operation at extremely low temperatures. Extreme caution must be used, however, when considering the use of these oils. Some are formulated for use only in gasoline engines and small and mid-range diesels. These oils meet API classification CC/SF. Other oils meet API classification CD/SE or CD/SF and may be used in heavy duty diesels subject to the engine manufacturer's approval.

The use of crankcase oil additives is not recommended as a means of reducing internal engine friction. All modern engine oils incorporate a variety of additives, each included for a specific purpose. Many oils already contain friction improvers and adding more seldom produces any cost-effective benefits. On the other hand, the extra additives may not be compatible with those already in the oil and this can have serious consequences.

The importance of consulting both the manufacturers of the engines and the oil supplier cannot be overstressed. While minimizing friction losses is most desirable, there are many other factors to be considered and the wrong choice of oil can prove to be very expensive in the long run.

10.3/ Engine-Driven Accessories

The accessories which are permanently connected to the engine can consume more than 40 hp.

The following is a summary of these power requirements for a typical line-haul diesel tractor:

Fan (28", @ 2100 rpm)	28 hp
Air compressor, pumping	5 hp
Alternator (full load)	3 hp
Power Steering Pump	- hp (3-4 hp during turns)
Air conditioner (operating)	6- 8 hp
	42-44 hp

None of this power helps to move the vehicle, so keeping these power requirements to a minimum will improve fuel economy.

10.3.1/ Fan

The largest consumer of power is the radiator fan, which, on a large tractor with a 36" fan, can consume more than 30 hp. Fan hp increases rapidly as engine and fan rpm increase, as shown in Figure 11. Fan noise also increases as rpm increases, and the power to create this noise is part of the total power consumed.

Tests have proved that even on a large diesel line-haul tractor, running in its upper power range much of the time, the fan is needed only 2 to 5% of the time. Replacing a fixed drive fan with a temperature-controlled

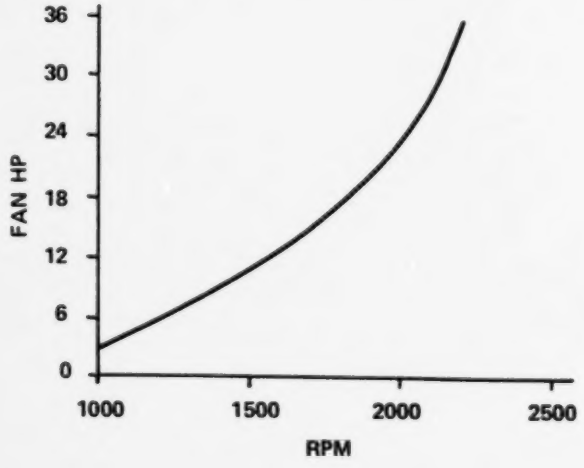


Figure 11/ Fan HP (28" Fan)

fan which absorbs power only when it is needed can save a lot of fuel -- as much as 8% in the case of a line-haul tractor; more in the case of an engine operating at high rpm but less than full power. Temperature-controlled fans also eliminate much of the noise associated with high engine speeds. For these reasons, temperature-controlled fans are now standard equipment on most vehicles of all types and sizes, and are mandatory on many vehicles to meet noise regulations.

These fans must be properly maintained like other vehicle components. Belt adjustment is important to avoid overloading the clutch hub bearings (or the water pump bearings in some installations) or to eliminate excessive slippage. The fan engagement temperature is critical, particularly when radiator shutters are fitted, and must be checked periodically.

It is important to obtain the engine manufacturer's recommendations concerning fan engagement temperatures for the particular types, makes and models of fans and engines concerned as these engagement temperatures are not the same for all combinations.

If a vehicle still has a fixed drive fan, consider replacing it with a temperature-controlled hub and lightweight fan. Subject to the concurrence of the engine manufacturer, an on/off clutch hub is recommended as it offers the greatest fuel savings (7% to 8% in line-haul service). Approximate installed cost of the complete assembly for a heavy duty diesel is $750 to $850.

If clutch or belt life is less than normal and a steel fan is fitted on an on-off clutch hub, consider replacing it with a lightweight fan.

10.3.2/ Alternator

Any unnecessary load on the alternator wastes fuel. The number of lights and electrically operated accessories should therefore be kept to a minimum and used only when necessary.

A check of the maximum normal continual electrical load will determine if the alternator has enough output capacity. This capacity should exceed

the normal electrical load by at least 20%. Check for electrical leaks (grounds) which add to the demand on the alternator.

Occasionally, a vehicle will be found which has an alternator with insufficient output. This may be the result of initial under-spec'ing, added electrical equipment, or the installation of an undersized replacement.

An under-capacity alternator will result in wasted fuel, more frequent repairs and higher maintenance costs. Batteries will not be kept fully charged, cranking power will be reduced, starting failures will be more frequent, and battery life will be shortened. Lack of confidence in starting ability inevitably leads to excess idling with wasted fuel and unnecessary engine wear.

10.3.3/ Air Compressor

Unnecessary operation of the compressor is another source of fuel waste. The primary cause of unnecessary pumping is excessive leakage, which also results in accelerated compressor wear. To determine if there is excessive leakage, the engine and compressor should be run until the compressor cuts out, the engine shut down, and the rate of drop in pressure measured.

The following are maximum rates of air loss recommended by the Ontario Trucking Association:

	With Brakes Off	With Full Brake Application
Single Vehicle (Tractor or Truck)	2 psi/min	3 psi/min
Two Vehicles (Tractor and 1 Trailer)	3 psi/min	4 psi/min
Three Vehicles (Tractor and 2 Trailers)	5 psi/min	6 psi/min

The two basic requirements for long, efficient compressor operation are clean oil and a clean air supply. Both should be supplied as part of a good maintenance program.

Driver behaviour has a significant effect on both compressor power requirements and wear.

Running the engine and compressor at high rpm immediately following a cold-start not only wastes fuel but causes excessive wear to both the engine and the compressor. Operating the engine at 1000-1200 rpm after start-up will result in less fuel and less wear, and the compressor will operate more efficiently at the lower speed. The extra time to build up air pressure is negligible compared to the benefits.

Pumping the brakes when slowing down is a wasteful practice which serves no useful purpose and causes unnecessary compressor operation.

10.3.4/ Engine Startability

The assurance that an engine will start promptly under all anticipated operating conditions is extremely important for several reasons:

- It minimizes the necessity or the excuse for idling the engine for long periods which wastes fuel and causes unnecessary wear.

- It minimizes starting failures which leave unburned fuel in the cylinders which, in turn, causes lube oil dilution and accelerated cylinder wall and ring wear.

- It minimizes the drain on the batteries and particularly deep discharging which shortens battery life and increases the load on the alternator.

- It minimizes the expense and delays resulting from starting failures, discharged batteries and burned-out starters.

- It ensures that vehicles will be available for use when needed.

Engine startability is a good indicator of the quality of maintenance and of driver knowledge and skill. Vehicles which are well-maintained and fuel efficient, with appropriate starting aids for the operating conditions concerned, are seldom difficult to start if the proper procedures

are used. Conversely, starting problems can be expected if engines are out of tune, batteries are poorly maintained, electrical connections have excessive resistance, the starting aids are missing or inoperative or the driver is not following the correct starting procedures.

In ambient temperatures above freezing, no problems should be encountered in starting engines using diesel, gasoline or propane fuel.

As the ambient temperature drops, engine cranking resistance increases while the cranking power of an electrical starting system decreases. This is illustrated in Figure 12.

There are many factors which affect startability, all of which become more critical at lower temperatures.

The cranking resistance of an engine depends upon its size, type of fuel and the type and grade of oil used. A particular problem in diesel engines is to obtain a high enough temperature in the combustion chambers

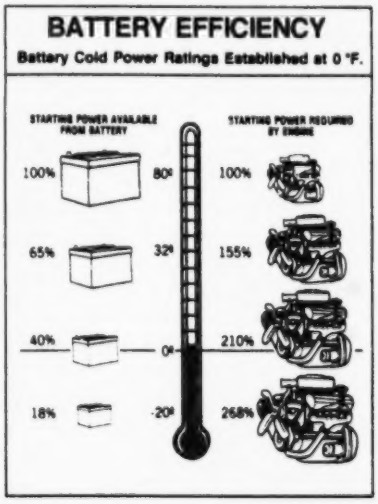


Figure 12/ Cranking Power vs Resistance
Source: Gould Manufacturing of Canada Ltd.

to ignite the fuel. This is determined by engine condition (compression), cranking speed and the ignition temperature of the fuel.

Low compression pressure is seldom a significant factor in low temperature starting because it also affects engine power and this will necessitate engine overhaul.

Cranking speed is critical in starting at low temperatures. In tests conducted at Kapuskasing during the winter of 1982 on a typical line-haul diesel, it was found that a minimum cranking speed of 125 rpm was required for starting. Moreover, if initial firing did not take place within five seconds, the engine would not start. Most manufacturers of line-haul diesels specify a minimum cranking speed in the 150-175 rpm range.

Cranking speed is determined by the characteristics of the particular engine oil and the cranking power of the starting system. Petroleum-based SAE 15W40 engine oil is widely used throughout Canada as an all-season engine lubricant. This oil, however, has too high a viscosity at low temperatures to permit a high enough cranking speed, even with a starting system in good condition.

To offset this condition, various means of lowering the viscosity by raising the temperature of the oil can be utilized. These include electric block heaters, gasoline or diesel fuelled cooling system heaters and, as a last resort, idling the engine either intermittently or continuously to keep the engine and oil temperature up. Electric oil pan heaters are also becoming more widely used; their main purpose is not to improve startability but to ensure the immediate supply of oil throughout the engine following start-up.

Both the engine manufacturers and the oil companies are well aware of the penalties related to low temperature starting and idling engines, which include both fuel waste and excessive engine wear.

New types and grades of oil are now available which will ensure startability with a minimum use of starting aids and idling. It is recom-

mended, therefore, that the engine manufacturers be consulted concerning the most cost-effective methods of ensuring startability.

Providing adequate cranking power for low temperature starting is, in most cases, a matter of good maintenance of the starting system. This involves ensuring:

1/ Adequate battery capacity -- a minimum of 1800 CCA for line-haul diesels with 12 V starting systems. More is desirable to prevent deep discharging of batteries and to compensate for deterioration with age and use.

2/ Good battery maintenance -- clean exteriors to prevent surface discharge, rubber pads and proper hold downs to minimize vibration. This is one of the major causes of poor battery performance and short life.

3/ Adequate battery temperature -- batteries not only lose cranking power as their temperatures drop, but develop increasing resistance to recharging. Both conditions can be minimized by using either an insulated electrically-heated battery blanket or by packing the battery box with rigid insulation such as styrofoam slabs.

4/ Minimum starting circuit resistance -- clean, tight connections throughout, including all ground return connections, combined with adequate cable sizes and ground straps. For minimum resistance, a cable direct from the starter motor housing to the ground side of the batteries is recommended.

5/ Efficient starting motor -- for low temperature starting, the cranking motor must be operating efficienctly. This requires that the bearings, brushes, commutator, reduction gears and pinion gear are all in good condition.

An alternative to electric starters are air starters. Air starters are becoming increasingly popular for a number of reasons, particularly where low ambient temperatures are prevalent, for the following reasons:

- Unlike electric starting systems, they do not lose cranking power at low temperatures.

- They provide higher engine cranking speeds at all temperatures, well in excess of the engine manufacturers' specifications.

- They reduce deep discharging of the batteries, lengthening battery life.

- They reduce the total battery and alternator capacity required.

- They reduce the frequency of repair and the total maintenance cost of the starting system.

For retrofitting, the cost of an air starting system, including cranking motor, a 2700 L (60 gal) air reservoir with mounting brackets, piping and fittings is approximately $1000 to $1200.

Last, but by no means least, and regardless of whether an electric or air starting system is used, the driver must follow the correct starting procedures.

The need for training drivers in low temperature starting techniques is evident from the number of companies which find it necessary to use mechanics for this purpose.

11/ MAINTAINING MINIMUM ROLLING RESISTANCE

Rolling resistance is made up of the resistance offered by the driveline, wheel bearings, brakes, wheel and axle alignment, wheel balance and tires.

Collectively, this resistance, even in a vehicle in first class condition, may require as much or more than half the power output of the engine at speeds up to 100 km/h (62 mph) (see Figure 4). Also, it usually involves more than 50% of vehicle maintenance expense. For maximum fuel efficiency, close attention must therefore be given to maintaining all these components in efficient condition.

The degree of success achieved in minimizing rolling resistance can be measured by means of a "coast-down test".

11.1/ Coast-Down Tests

The purpose of a coast-down test is to determine how far a vehicle will roll without power under a given set of conditions.

Coast-down tests are not only useful to the maintenance department as a means of comparing overall vehicle rolling resistance but can also be used to demonstrate to drivers and others the effects on rolling resistance of radial vs bias-ply tires, underinflated tires, heavy vs light transmission and rear axle lubricants, and other variables.

These tests can be conducted on any stretch of road -- level, uphill or downhill -- provided the same stretch of road is used and the operating conditions (wet or dry road, direction and velocity of wind, etc.) remain the same or do not vary significantly. A straight stretch of smooth, level road is preferred.

Ambient temperature is important, as is thoroughly warming up the complete power train to operating temperature. Rolling resistance will obviously be greater when the transmission, axle and wheel bearing lubricants and the tires are cold. Rolling resistance is also affected by weight, so the gross weight of a vehicle must be the same when a test is comparing the effects of a change on a vehicle.

Coast-down tests can be carried out either separately or as part of a pre-inspection or post-inspection road test. They can be performed from either a running or standing start.

Running starts are used on level or uphill roads; standing starts for downhill tests.

When a running start is used, the vehicle is brought up to a specified speed such as 60 km/h (35 mph) at a designated starting point, where the engine is declutched and the vehicle is allowed to coast to a standstill. This point is then identified by means of a convenient nearby landmark. The longer the distance the vehicle has coasted, the less the rolling resistance.

Downhill tests are conducted from a standing start and the vehicle is allowed to accelerate with the engine declutched. The speed attained when it passes a designated point is then noted. The higher this speed, the less the resistance.

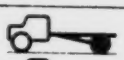
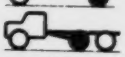
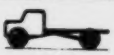
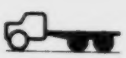
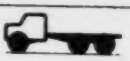
It should be noted that tests involving high speeds, either at the start or finish, include the effect of aerodynamic drag on the vehicle concerned and this must be taken into consideration when evaluating the results.

It must be emphasized that coast-down tests are not sufficiently accurate to be used as the basis for management decisions concerning the cost-effectiveness of various options such as tires and lubricants.

11.2/ Drive Trains

The drive train (clutch, transmission, drive shaft and drive axles) can absorb up to 25% of the power delivered by the engine, depending on vehicle design and weight, selection of drive train components and other factors as indicated in Figure 13.

DRIVELINE LOSSES AND EFFICIENCY FACTORS

Chassis Type	Transmission Speeds		% Loss of	Driveline
	Main	Auxiliary*	Power & Torque	Efficiency
4 x 2 	4 to 6	None	10%	.90
6 x 2 	8 to 16	None	15%	.85
	4 or 5	2 to 4	16%	.84
4 x 4 	4 to 6	1 to 2	15%	.85
6 x 4 	4 to 6	None	15%	.85
	8 to 16	None	18%	.82
	4 or 5	2 to 4	20%	.80
6 x 6 	4 to 6	2 to 4	25%	.75

Note: *Auxiliary transmission or transfer case.

Figure 13/ Driveline Losses

Source: Truck Marketing Institute

These power losses are caused, for the most part, by friction and by churning of the lubricants in the transmission and axle gearing and wheel bearings. Therefore, the selection of lubricants for these components will affect the amount of power lost and the fuel efficiency of the vehicle.

There are a number of important factors to be taken into consideration when choosing these lubricants. These include the lowest and highest anticipated ambient temperatures, the type of service and, most important, the lubricant specifications of the transmission and axle manufacturers. Particular care must be taken in the case of certain transmissions and rear axles made by Mack Trucks which require special lubricants.

Transmission and differential lubricants are available in both SAE single and multi-grades, but not all oil companies offer all grades.

To add to the complexity of selecting lubricants for these components, petroleum-, partial- and all-synthetic-base products are available, sometimes in the same SAE grade.

In general, the partial- and all-synthetic-base oils are slightly more fuel efficient than the petroleum-base products (tests have shown fuel savings of 1-2%), but are more expensive. A multi-grade, if it eliminates seasonal lube changes, can save both vehicle downtime and expense. Other considerations are the space requirements, extra inventory investment and the risks of mis-application of a variety of lubricants.

The objective should be to select the most fuel-efficient lubricant(s) which will result in the most cost-effective operation.

Another cause of driveline inefficiency is vibration resulting from faulty assembly or excessive wear. To create vibration requires energy which, in a motor vehicle, can come only from the fuel. Vibration, moreover, causes accelerated wear and higher repair costs.

For maximum fuel efficiency and minimum long-term costs, vibration in the driveline must be kept to a minimum. This requires close attention to U-joint phasing and angularity, driveshaft balance and the prompt replacement of worn parts.

In the case of low rpm diesels (2100 rpm and below), torsional vibrations created by the variable rotational speeds of the crankshaft can accelerate driveline wear if the clutch has solid discs. For this reason, damping type clutch discs should be used, containing springs which absorb the vibrations. They cost approximately $60 more than solid discs when purchased as replacements, but this will be recovered in extended drivetrain life and reduced frequency and duration of downtime.

11.3/ Brakes

Dragging brakes waste fuel and result in excessive lining and drum wear. In severe cases, they may also cause cracked drums and the excessive heat can damage wheel bearings and shorten tire life.

Brakes must release quickly and completely. Parts requiring attention include:

- shoes sticking on anchor pins;
- sticking camshafts which do not rotate freely;
- weak brake shoe retracting springs;

- worn blocks or linings and/or oversize drums which permit the camshafts to over-rotate;
- sticking disc brake pads;
- sticking quick-release valves; and
- parking brakes on vehicles without spring brakes which do not release completely.

11.4/ Wheel Bearings

Grease lubricated wheel bearings can increase rolling resistance, particularly at low ambient temperatures, and conversion to oil lubrication is recommended for this reason. Either gear oil or engine oil can be used, but the two types should not be mixed. The following grades are recommended:

Gear Oil -- API GL-5 performance level		
	Above -18°C (0°F)	SAE 90 or 75W/90
	Below -18°C (0°F)	SAE 75W or 75W/90
Engine Oil -- all API classifications		
	Above -18°C (0°F)	SAE 50, 40 or 15W/40
	Below -18°C (0°F)	SAE 30 or 5W/30

It is advisable to check with the oil seal supplier to ensure that the proposed lubricants are compatible with the materials used in the seals.

11.5/ Tires and Wheels

At speeds under 100 km/h tires are usually the largest single consumer of power and fuel. Moreover, in most fleets, after labour and fuel, tires are the largest maintenance expense. Tire maintenance is therefore a major factor in minimizing both fuel and maintenance costs.

An effective tire maintenance program involves:
- on-vehicle maintenance;
- off-vehicle maintenance; and
- upgrading.

11.5.1/ On-Vehicle Maintenance

The objective of on-vehicle maintenance is to ensure that the tires on a vehicle will continue to perform safely and efficiently, and to identify and correct any condition which will increase rolling resistance or shorten the potential life of the tires.

The biggest enemy of both fuel efficiency and tire life is underinflation, as indicated on the graphs in Figure 14.

Overinflation, while it will result in a slight increase in fuel efficiency, is not recommended because the disadvantages outweigh the advantages. These disadvantages include reduced traction, uneven and faster tread wear, reduced shock resistance, less resistance to cuts and punctures, a harder ride, and increased damage to the vehicle and its loads.

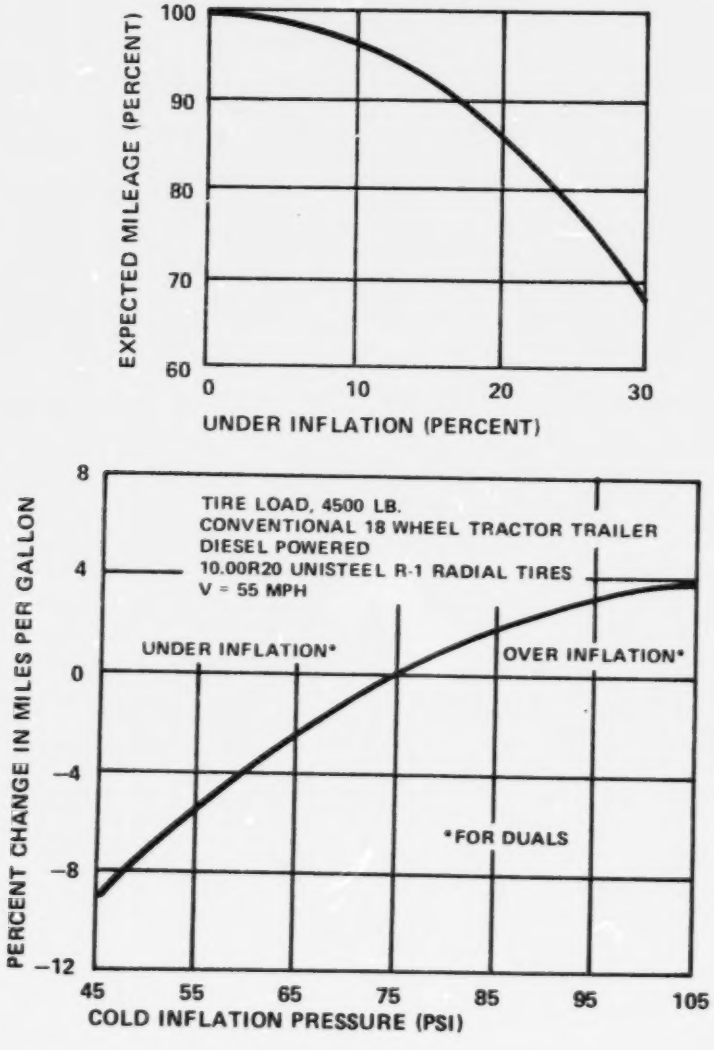


Figure 14/ The Effects of Tire Inflation on Fuel Economy and Tread Wear
Source: Goodyear Canada, Inc.

The correct inflation pressure is determined by the maximum load (not the average or typical load) to be carried by the tire. The inflation pressure shown on the sidewall of the tire is, on the other hand, the pressure required when the tire is carrying its full rated load which may be much higher than the actual maximum loads.

If the actual maximum load on a tire is less than its rated capacity, the correct pressure will be less than the sidewall pressure, and using the sidewall pressure will result in an overinflated tire.

The correct pressure can, however, be determined from the load-inflation tables published by the tire manufacturers and available from their distributors and dealers. An example is shown in Figure 15.

DUAL (D) SINGLE (S)

TIRE SIZE DESIGNATION			TIRE LOAD LIMITS (LB) AT VARIOUS COLD INFLATION PRESSURES (PSI) (THE PRESSURE IS THE MINIMUM FOR THE LOAD)											
			75	80	85	90	95	100	105	110	115	120		
8.25R15TR 9R17.5HC	OR	D S					3040 3200	3150 3340	3260(F) 3470	3360 3590	3470 3720(F)	3570(G) 3830	3960	4070(G)
8.25R20 9R22.5	OR	D S		3270 3370	3410 3560	3550(E) 3730	3690 3890	3820 4050(E)	3950(F) 4210	4350	4500(F)			
9.00R20 10R22.5	OR	D S	3690 3770	3870 4000	4040(E) 4210	4200 4410	4360 4610(E)	4520(F) 4790	4670 4970	4820 5150(F)	4970(G) 5320	5490	5670(G)	
10.00R15TR 11R17.5HC	OR	D S		3660 3780	3830 3980	3980(F) 4170	4130 4370	4280 4540(F)	4430(G) 4710	4880	5050(G)			
10.00R20 11R22.5	OR	D S		4380 4530	4580 4770	4760(F) 4990	4950 5220	5120 5430(F)	5300(G) 5640	5470 5840	5630 6040(G)	5800(H) 6240	6430	6610(H)
10.00R22 11R24.5	OR	D S		4660 4820	4870 5070	5070(F) 5310	5260 5550	5450 5780(F)	5640(G) 6000	5820 6210	6000 6430(G)	6170(H) 6630	6840	7030(H)
11.00R20 12R22.5	OR	D S		4780 4940	4990 5200	5130(F) 5450	5390 5690	5590 5920(F)	5780(G) 6140	5960 6370	6150 6590(G)	6320(H) 6790	7010	7200(H)
11.00R22 12R24.5	OR	D S		5080 5240	5300 5520	5520(F) 5790	5730 6040	5940 6290(F)	6140(G) 6530	6330 6770	6530 7000(G)	6720(H) 7220	7440	7660(H)
11.00R24		D S		5390 5570	5630 5860	5860(F) 6140	6090 6420	6310 6680(F)	6520(G) 6940	6730 7190	6930 7430(G)	7130(H) 7670	7900	8138(H)

NOTES:
1. LETTERS IN PARENTHESES DENOTE LOAD RANGE FOR WHICH LOADS (SHOWN IN COLOR) ARE MAXIMUM.
2. ADJUSTMENTS ARE INCLUDED IN THE ABOVE COLD INFLATION PRESSURES FOR VEHICLE SPEED UP TO 70 MPH EXCEPT THAT LOADS IN CROSS-HATCHED AREA ARE LIMITED TO MAX SPEED = 60 MPH.
3. AN ADDITIONAL 10 PSI COLD INFLATION IS RECOMMENDED TO COMPENSATE FOR PRESSURE LOSS BETWEEN AIRINGS. HOWEVER, IN NO CASE SHOULD RIM LOAD AND INFLATION LIMITS BE EXCEEDED.
4. ABOVE TABLE IS BASED ON TIRE & RIM ASSOCIATION TABLES TB-1R AND TTB-1R WITH PERMITTED ALLOWANCES.
5. NOTES SHOWN ON PAGE 338 MUST BE USED FOR THE ABOVE TABLE.

Figure 15/ Tire Inflations Recommended for Highway Service on Radial Tires -- Trucks, Buses & Trailers
Source: Goodyear Canada Inc.

It is important, therefore, for safety, maximum fuel efficiency and minimum long-term tire costs that the maximum service load on each tire and the corresponding inflation pressure be determined. These pressures should then be used as standard pressures when checking tires and should be readily available in the form of a list or marked on the vehicles near the tires.

Many tires will lose a little pressure in service. To offset this loss, and because underflation is more damaging than overinflation, the Tire and Rim Association recommends inflating tires 10 psi above the correct pressure as insurance against the tires becoming under-inflated before the next pressure check.

With or without this extra 10 psi, **no tire should ever be inflated to a higher pressure than the capacity of the rim on which it is mounted.**

The basic elements of a good on-vehicle tire inflation program are:

- Knowledge of the correct pressure for each tire.

- Frequent tire pressure checks and visual inspections -- at least every two weeks; more often if more than an occasional tire is found to be underinflated or if frequent damage is found; less often if defects are rarely found. It is recommended that the maximum interval should be no longer than one month.

- Accurate tire pressure gauges -- service gauges are subject to a lot of abuse and should be checked weekly against a master gauge. Any service gauge with an error of more than ±5 psi should be replaced (cost is approximately $20). A master gauge, used only to check service gauges, costs approximately $30 to $80, depending on the make and model.

- Metal or nylon sealing-type valve caps -- these are a must. The valve core is only intended to hold the air in a tire until a sealing-type cap can be installed. These caps will hold 200 psi indefinitely. Many common black caps are made of plastic and have no seal, and therefore will not prevent the loss of air. Metal sealing-type caps cost approximately $15 per hundred. The dome-style caps are preferred to the slotted-top style as they minimize the chance of hand injuries.

- Tread depth gauges -- these are necessary to determine when tires should be removed for retreading and when legal wear limits are reached (cost approximately $5).

Legal minimum tread depths for truck tires are:

Fronts	3 mm (4/32")
Rears	1.5 mm (2/32")
Trailers	1.5 mm (2/32")

- Tire pressure records -- these are essential in order to determine the loss of pressure between checks. It is recommended that any tire with a sealing-type valve cap which has lost 5 psi or more during a two-week period be removed immediately and the cause identified and corrected.

When checking tire inflation pressures, the following precautions must be observed.

- Never rely on visual appearance or striking tires with a bar to judge inflation pressure. In the case of radials, the loss of as much as 50 psi is not obvious. Tests conducted with bars showed that even so-called "experts" could not identify tires which were underinflated by as much as 20 psi. An accurate service gauge must be used and **every tire** should be gauged.

- Tires must be cold -- the heat generated when tires are rolling will increase the normal pressure of automobile tires by as much as 4 psi and truck tires by up to 15 psi. Allow a cool-down period of at least two hours for tubeless tires and three hours for tube-type tires. A tire which has run more than 1.5 km (approx. 1 mi) is not cold.

- Check rated air pressures of rims -- never inflate tires above these pressures. If the correct tire pressure exceeds the maximum rim pressure, the rim should be changed.

In a fleet with a good tire inflation and maintenance program, a check of pressures will show 95 to 100% of tires to be within 5 psi of their correct pressures.

Maintaining correct tire pressures will not, by itself, result in maximum fuel efficiency and minimum tire costs. It is important that the following on-vehicle checks also be made.

- Treads, sidewalls, and rims should be examined for signs of damage. Damaged tires should be removed and any damage repaired promptly. This is particularly important in the case of all-steel radials.

- Matching of duals should be checked. Permissible variances are:

  8.25-20TT (9-22.5TL) and smaller -- 6 mm (0.25") diameter
  19 mm (0.75") circumference

  9.00-20TT (10-22.5TL) and larger -- 13 mm (0.5") diameter
  38 mm (1.5") circumference

  Smaller tires should be located on the inside positions for minimum drag and tread wear.

  Even with only 38 mm (1.5") difference in circumference between duals, the smaller tire will be skidded along the road surface approximately 12 m for each kilometre travelled (65 ft for each mile) -- an obvious waste of energy and tread rubber. Duals should therefore be matched to closer limits whenever possible.

  In the case of tandem driving axles, the difference in the diameter or circumference of the tires on the two axles should not exceed 6 m (0.25") in diameter or 19 mm (0.75") in circumference, regardless of tire size.

- Spacing between duals should be checked -- there should be a minimum of 25 to 38 mm (1 to 1.5") between the bulges at the bottom of the tires. Consult the tire supplier for the recommended spacing for particular tires.

- Tires should be removed for retreading or reconditioning before the minimum tread depths have been reached. While rolling resistance decreases slightly as the tread gets thinner, so does bruise resistance. When the tread approaches minimum thickness the risk of damage to the belts and plies from stones, pot holes, etc. increases significantly.

Removal for retreading is therefore recommended when the tread depth is 5 mm ($^{6}/_{32}$") on front tires and 3 mm ($^{4}/_{32}$") on other tires. The long-term savings from retreading will more than offset the possible extra mileage from the remaining tread. An alternative for front tires is to move them to another location when they wear down to 5 mm.

- The treads of all tires should be examined for evidence of uneven wear. Particular attention should be paid to evidence of incorrect toe settings and axle misalignment, which cause additional rolling resistance and tread wear.

- If uneven front tire tread wear is evident, the suspension and steering mechanism should first be checked for excessive play. If the vehicle is operated at highway speeds, wheel balance should also be checked and corrected as necessary. Front end alignment should then be checked. General recommendations for an unloaded vehicle with 20" or larger wheels are:

Toe-in	$^{1}/_{32}$" ± $^{1}/_{32}$"
Camber	+ $^{1}/_{8}$° ± $^{1}/_{4}$°
Caster	+ 2 $^{1}/_{2}$°. Max variation between wheels, $^{1}/_{2}$°

Exact front end alignment settings for individual unloaded vehicles should be obtained from the vehicle manufacturers.

Excessive toe-in or toe-out can increase rolling resistance, increase fuel consumption, shorten tread life and affect ride and handling characteristics. Even a tire with only $^{1}/_{16}$" toe-out is being dragged sideways approximately 2.5 m for each kilometre travelled (8 feet for each mile). The effect of toe-in/toe-out on tread life is shown below:

Toe-in (inches)	Tread Life (%)
$^{1}/_{32}$"	100
$^{1}/_{8}$	82
$^{1}/_{4}$	76

Source: Goodyear Canada Inc.

- Other tires -- if uneven tread wear is noted, first check and correct any looseness in the suspension. If the vehicle is operated at highway speeds, balance the tires as required.

- Axle alignment -- all axles must be exactly parallel to each other and at right angles to the vehicle centreline to minimize rolling resistance and provide maximum tread life, as indicated in Figure 16.

  Axle alignment should be checked after any frame or suspension damage and after the replacement of any suspension components which may affect the alignment.

  Several of the major tire manufacturers have developed special equipment and procedures for checking axle alignment and can provide expert assistance.

- Tire rotation, i.e., moving tires from one location on the vehicle to another, will not significantly improve vehicle efficiency but should be used, when necessary, to equalize tire wear and to take maximum advantage of retreading.

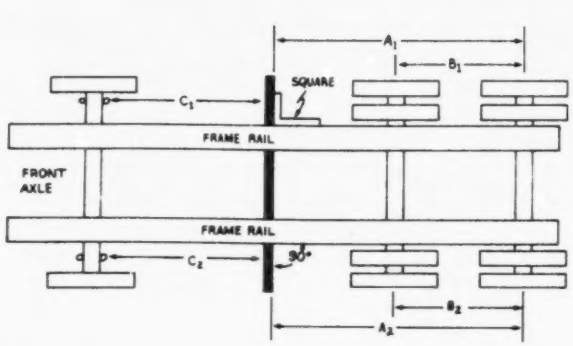


Figure 16/ Axle Alignment

Source: Goodyear Canada Inc.

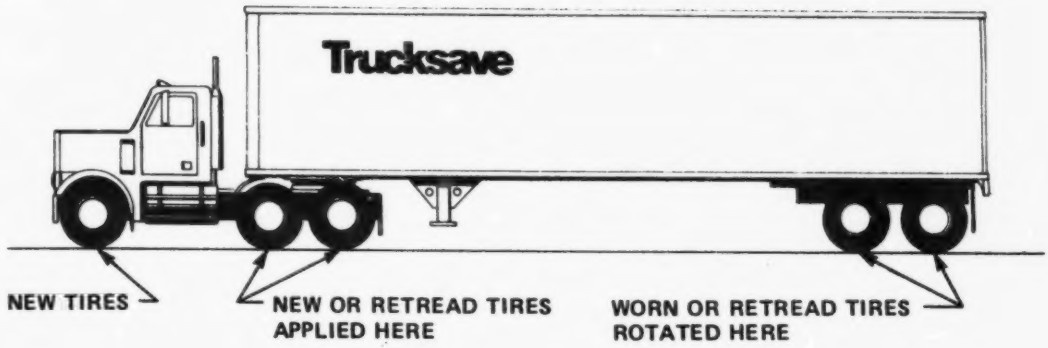


Figure 17/ Tire Rotation

Source: Goodyear Canada, Inc.

When rotating tires, the rules concerning mixing bias ply and radial ply tires must be followed. The rule that radial tires must always rotate in the same direction no longer applies because improvements in tire construction have made this unnecessary. The recommended pattern which should be followed for rotating tires is shown in Figure 17.

- Check mixing of bias ply and radial tires on each vehicle. The following guidelines should be followed, except in emergencies. In such cases, the vehicle must be driven with extreme caution as vehicle handling may be unpredictable and dangerous.

  1/ Passenger cars and light trucks (wheels under 16")
  - -- Never mix radial and bias ply tires on these vehicles.
  - -- All tires must be of the same size and aspect ratio.

  2/ Light trucks (16"-19" wheels)
  - -- Never mix radial and bias ply tires on the same axle.
  - -- If the vehicle has single rear tires, never put radial tires on the front axle only.
  - -- If the vehicle has dual rear tires, radials or bias ply tires may be used on either axle. According to one major manufacturer, the use of bias ply tires on the front will result in the best vehicle handling.

3/ Medium and heavy trucks (20" and larger wheels and including trailers with 15" wheels)

-- Never mix radial and bias ply tires on the same axle.
-- Never mix radial and bias ply tires on a tandem drive-axle combination.
-- If a two-axle vehicle has dual rear tires, radial or bias-ply tires may be used on either axle. Here again, one major manufacturer advises that the vehicle handles best with the bias ply tires on the front.
-- If the vehicle has three or more axles, either bias ply or radial tires may be used on the front axle, with either all bias ply or radial tires on the non-steering axles.

If a vehicle is found which does not conform to these guidelines, it should have the proper tires installed without delay.

11.5.2/ Off-Vehicle Tire Maintenance

Fuel and tire costs can be minimized by a combination of tire conservation and the introduction of more fuel-efficient and cost-effective replacement tires.

Tire conservation involves prompt, high quality repairs, retreading or reconditioning whenever practicable, selection of correct rims, followed by correct mounting of tires on wheels and rims and installation of the wheels and rims on the vehicles.

Approximately 70% of the cost of a tire is in the casing, with the remaining 30% in the original tread. It is only good economic sense to obtain the maximum possible life out of both components and therefore to retread the casing as often as its condition allows. A new tread can give as much mileage as the original (sometimes more) for about a third of the cost of a new tire.

If tires are coming into the shop with cuts, tears or abrasions which have obviously existed for some time, the on-vehicle inspection is not doing its job. All tire casings (particularly tires with steel cords) must be removed for repair before moisture and dirt cause internal damage. Prompt action can extend the life of a casing several times over.

Retreading and reconditioning are now proven and accepted procedures for extending the useful life of tire casings at minimum cost.

Retreading involves removing the remainder of the original tread from the casing and applying new tread material. There are many reputable retreading firms but one major tire manufacturer has found it necessary to issue the following warning:

Belt Removal During Retreading

It has come to our attention that some retreaders are removing crown plies from radial truck tires during the retreading process.

Steel belted radial truck tires are designed and manufactured to give high performance and quality. When a structural component like a steel crown ply is removed, it is important that it be replaced with a similar component so as to maintain the designed function of the tire. This can only be done by a specific and precise process requiring special equipment and carefully selected materials.

Failure to carry out this procedure properly will result in irreparable damage being done and the resultant tire will be unsuitable for the purpose for which it was designed.

Retreading costs vary according to the firm doing the work, the tread compounds used and other factors. Cost is typically 30% that of a new tire.

Reconditioning is offered by a number of the major tire manufacturers and is conducted on an exchange basis which minimizes delays in obtaining replacement tires. The cost of a reconditioned tire is determined by the amount of work which must be performed on the tire turned in, and ranges

from 25-50% of the cost of a new tire. Manufacturers engaged in reconditioning accept only their own tires for this operation.

Both retreading and reconditioning offer a variety of ways to improve tire inventory by selecting tread patterns and compounds which will best meet future needs. Compounds can be selected which reduce rolling resistance to less than that of the previous treads and therefore improve vehicle fuel efficiency.

Retreading and reconditioning of radial tires are particularly attractive because of the higher initial cost of these tires (approximately 30% more than bias ply tires). The basic advantages of radials more than justify this extra cost, but with one or more retreads, tire cost per kilometre can also be reduced significantly as illustrated in Figure 18.

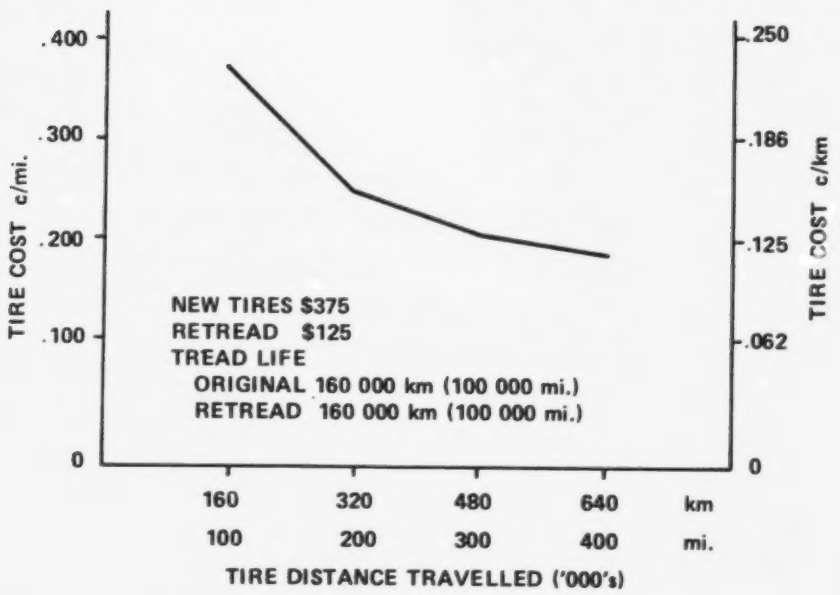


Figure 18/ Tire Costs with Retreading
Source: TruckSave

Other off-vehicle maintenance considerations which are important to both fuel efficiency and to minimizing costs are listed below.

- Tubes and flaps used with radial tires are different from those used with bias ply tires. Care must be exercised when selecting tire components for assembly.

- Old stretched tubes should not be used in new or newly retreaded or reconditioned tires. The tube could be pinched, leading to the premature loss of the tire.

- Rim widths must be matched to the tire. Over- or under-width rims can result in damage to the bead area of the tire, high tread wear rates, excessive flexing and heat, and poor vehicle handling.

- Tire pressures must not exceed the rated air pressures of the rims on which they are mounted. Rated rim pressures can be obtained from the wheel manufacturers' manuals. This is particularly important when mounting radials which require higher pressures than bias ply tires for the same load.

- Rims should be free of cracks, rust and corrosion. Rims should be thoroughly wire brushed as soon as tires are removed. If any cracks or pitting are found after brushing, the rim should be discarded. Otherwise, a metal paint should be applied to the rim to inhibit future corrosion. A cracked or pitted rim can be dangerously weak.

- Use an approved bead lubricant when mounting tires on rims. Soap solutions and water-based mixtures cause rusting of rims and steel cords in tires. Petroleum-based lubricants damage tires, tubes and flaps.

- Bead lubricant should also be used when demounting tires from rims. Tire demounting tools can damage dry bead surfaces, resulting in future leakage, underinflation, wasted fuel and premature tire failure.

- After tires have been mounted on rims or wheels, they should be inflated to seat the tire beads; the air should then be released and the tire re-inflated to the required pressure. The date and the exact pressure should be marked on the sidewall and a sealing-type valve cap applied.

- Before installing a tire and wheel or rim assembly from stock on a vehicle, the pressure should be checked. If it has lost air since it was mounted on the rim it should not be installed until the leak has been corrected.

- When mounting rims and disc wheels, run-out should be kept to a minimum by ensuring that the mating surfaces are clean and that the nuts are tightened in the correct sequence to the specified torque. Maximum run-out, measured at the widest part of the tire, should not exceed $^{1}/_{16}$" for front wheels and $^{1}/_{8}$" for others.

- The rim or wheel nuts should be retorqued after 80 to 160 km (50 to 100 mi) of vehicle operation. Failure to take this precaution may result in damaged wheels, broken studs and even serious accidents.

- The shop air supply should be clean and dry. Moist air will penetrate into tire carcasses and corrode steel cords. It can also cause separations in any tire when the tire gets hot. The same moisture will accelerate rim corrosion. Oil in the air supply will damage the tire casings, tubes and flaps.

- When installing dual tires, the difference in diameters or circumference must be within limits and the smaller tire should be inside. Within these limits, the less difference the better for both minimum rolling resistance and maximum tread life.

- When a tire stored in a warm shop is installed on a vehicle in winter ambient temperatures, the pressure should be checked after the vehicle has been standing outside for at least two hours and adjusted as required. Alternatively, extra air should be added to compensate for the loss of pressure when the tire has cooled to ambient temperature. The amount of extra pressure required is shown in Figure 19.

- The operations supervisor concerned should be advised of any instance of tire neglect or abuse which is affecting fuel efficiency or tire life.

RECOMMENDED INFLATION PRESSURE PSI (kPa)	OUTSIDE AMBIENT TEMPERATURE °F (°C)											
	65 (18)	50 (10)	40 (4)	30 (-1)	20 (-7)	10 (-12)	0 (-18)	-10 (-23)	-20 (-29)	-30 (-34)	-40 (-40)	-50 (-46)
30 (210)	30 (210)	31 (210)	32 (220)	33 (230)	34 (230)	35 (240)	36 (250)	37 (260)	39 (270)	40 (280)	41 (280)	43 (300)
35 (240)	35 (240)	36 (250)	37 (260)	38 (260)	40 (280)	41 (280)	42 (290)	43 (300)	45 (310)	46 (320)	47 (320)	49 (340)
40 (280)	40 (280)	42 (290)	43 (300)	44 (300)	45 (310)	46 (320)	48 (330)	49 (340)	51 (350)	52 (360)	54 (370)	55 (380)
45 (310)	45 (310)	47 (320)	48 (330)	49 (340)	51 (350)	52 (360)	53 (370)	55 (380)	57 (390)	58 (400)	60 (410)	62 (430)
50 (350)	50 (350)	52 (360)	53 (370)	55 (380)	56 (390)	58 (400)	59 (410)	61 (410)	62 (430)	64 (440)	66 (460)	68 (470)
55 (380)	55 (380)	57 (390)	58 (400)	60 (410)	61 (410)	63 (430)	65 (450)	67 (460)	68 (470)	70 (480)	72 (500)	75 (520)
60 (410)	60 (410)	62 (430)	64 (440)	65 (450)	67 (460)	69 (480)	71 (490)	72 (500)	74 (510)	77 (530)	79 (550)	81 (560)
65 (450)	65 (450)	67 (460)	69 (480)	71 (490)	72 (500)	74 (510)	76 (520)	79 (540)	80 (550)	83 (570)	85 (590)	87 (600)
70 (480)	70 (480)	72 (500)	74 (510)	76 (520)	78 (540)	80 (550)	82 (570)	84 (580)	86 (590)	89 (610)	91 (630)	94 (650)
75 (520)	75 (520)	78 (540)	79 (550)	81 (560)	83 (570)	85 (590)	88 (610)	90 (620)	92 (640)	95 (660)	97 (670)	100 (690)
80 (550)	80 (550)	83 (570)	85 (590)	87 (600)	89 (610)	91 (630)	93 (640)	96 (660)	98 (680)	101 (700)	104 (720)	107 (740)
85 (590)	85 (590)	88 (610)	90 (620)	92 (640)	94 (650)	97 (670)	99 (680)	102 (700)	104 (720)	107 (740)	110 (760)	113 (780)
90 (620)	90 (620)	93 (640)	95 (660)	97 (670)	100 (690)	102 (700)	105 (720)	107 (740)	110 (760)	113 (780)	116 (800)	118 (810)
95 (660)	95 (660)	98 (680)	100 (690)	103 (710)	105 (720)	108 (750)	110 (760)	113 (780)	116 (800)	119 (820)	122 (840)	125 (860)
100 (690)	100 (690)	103 (710)	106 (730)	108 (750)	111 (770)	113 (780)	116 (800)	119 (820)	122 (840)	125 (860)	129 (890)	132 (910)
105 (720)	105 (720)	106 (750)	111 (770)	113 (780)	116 (800)	119 (820)	122 (840)	125 (860)	128 (880)	131 (900)	135 (930)	139 (960)
110 (760)	110 (760)	114 (790)	116 (800)	119 (820)	122 (840)	125 (860)	128 (880)	131 (900)	134 (920)	138 (950)	142 (980)	145 (1000)

NOTE: Do not exceed maximum rim pressure limitations.

NOTE: For inside temperatures other than 18°C (65°F), determine difference between inside and outside temperatures and use this difference.

Figure 19/ Adjusted Inflation Pressure When Inflating Indoors at 18°C
Source: Michelin Tires (Canada) Ltd.

11.5.3/ Upgrading Tire Fuel Efficiency

The advantages of radial tires have now been well established for all types of service in which the full potential life of the tire casing can be realized.

This was not always the case. Many fleets had unfortunate experiences when they first tried radials and do not want to get their fingers burned twice. Misunderstandings concerning mixing bias ply and radial tires have also delayed some fleets from converting their present vehicles to radials, although they may be spec'ing these tires on their new vehicles.

For fleets which are still buying bias ply replacement tires, the switch to radials may offer immediate and significant fuel savings, fewer punctures, longer tire life and lower tire costs -- all valuable advantages. For these reasons, Trucksave does not hesitate to recommend that every fleet using bias-ply tires investigate the benefits of phasing them out as replacements are needed. Tests have shown the fuel savings typical of radial tires (see Figure 20).

LOADING CONDITIONS		55 MPH	65 MPH
Fully Loaded	(GCW = 56 800 kg (125 000 lb))	17.2%	-
Fully Loaded	(GCW = 36 300 kg (80 000 lb))	11.6%	8.4%
Partially Loaded	(GCW = 20 500 kg (45 000 lb))	7.2%	5.3%
Empty	(GCW = 13 600 kg (30 000 lb))	4.6%	3.0%
Average of Fully Loaded & Empty		8.1%	5.7%

Figure 20/ Gain in Fuel Economy Due to Use of Radial Ply Tires
Source Goodyear Canada Inc.

The changeover to radials should be carefully planned in advance to obtain the maximum benefits as early as possible. Some factors to be considered are:

1/ The rules for mixing radials and bias ply tires must be followed.

2/ Rims must have the capacities for the higher pressures of radial tires.

3/ Heavily loaded vehicles will benefit more than those that are lightly loaded.

4/ High mileage vehicles will benefit more than low mileage vehicles.

5/ Faster vehicles will benefit more than slower ones (but high speeds waste fuel and increase maintenance costs -- a maximum of 90 km/h is recommended for all vehicles).

6/ In the case of 18-wheel tractor-trailer combinations, converting the trailer to radials will save more fuel than converting the tractor -- give trailers first priority.

7/ The least expensive conversions involve changing only the tires. Going from tube-type bias ply to tube-type radials involves only the tires, while converting from tube-type bias ply tires to tubeless radials requires new rims or wheels.

8/ Tubeless tires are slightly more fuel efficient than tube-type (radials and bias ply) but the additional fuel savings may not offset the cost of new rims or wheels.

9/ Tube-type radial tires require different tubes and flaps than tube-type bias ply tires.

10/ Low profile and wide base single radials offer progressively additional fuel savings in certain applications.

11/ The degree to which conversion should be extended depends on how long the vehicles will be kept, future mileages, vehicle resale values, cost of financing replacements and other factors. Tire upgrading costs for present vehicles which would not have been considered worthwhile a few years ago, may be justified now.

12/ Outside help in planning and carrying out a changeover is available from tire suppliers and from the tire manufacturers. Full advantage should be taken of this assistance.

12/ MINIMIZING AERODYNAMIC DRAG

Aerodynamic drag is a major consumer of power and fuel at highway speeds. Moreover, the power required to overcome aerodynamic drag increases as the cube of the speed, which means that doubling the speed from 50 km/h to 100 km/h (approximately 30 to 60 mph) requires eight times the air resistance horsepower (see Figure 4).

This extra power is reflected in higher fuel costs and in accelerated wear of the engine, drivetrain components, brakes and tires which results in higher maintenance costs.

There is also a direct relationship between higher speeds and the frequency and severity of accidents, which add to the workload on the maintenance department and to both maintenance and insurance costs.

The effect of drag reducing devices on the fuel efficiency of a vehicle depends on many factors including:

- vehicle speed;
- wind speed and direction;
- proportion of time or distance the vehicle operates at various speeds;
- vehicle configuration;
- type of device;
- design and effectiveness of a particular device compared to similar competitive products; and
- positioning of the device on the vehicle.

Various combinations of some of the factors listed above can reduce the effectiveness of some devices to zero or, even worse, to a negative value so that the device is actually causing an increase in fuel consumption instead of a reduction.

For this reason, the operations department must continually monitor the utilization of vehicles equipped with drag-reducing devices, and the maintenance department should not continue to inspect and repair these devices on the assumption that this expense is being recovered in fuel savings.

As an example, a line-haul tractor comes into the shop for inspection... this tractor is equipped with a roof-mounted air deflector because it was used to pull 4.1 m (13.5 ft) van trailers. For some reason, however, the tractor is now pulling more tanks and flatbeds than vans and not all the vans have the same height and kingpin location. This tractor would now be more fuel efficient if the deflector was removed.

If drag-reducing devices are to improve fuel efficiency and be cost-effective, continual checking is necessary by both operations and maintenance to ensure that they are producing the desired results.

For those vehicles where this has been established, the maintenance procedures described in Section 12 are recommended.

12.1/ Cab Roof-Mounted Air Deflectors

The areas requiring maintenance attention are the cab roof, the fastenings which secure the device to the roof, the position of the deflector and the deflector itself.

These areas should be inspected at regular intervals and corrective action taken as required.

Particular attention should be paid to the cab roof where inadequate reinforcing, excessive jolting or vibration can cause fracturing of the roof panel. All fastenings must be kept tight and those used to change the position of deflector must not be allowed to seize up. Any difficulty encountered in changing the position of the deflector may result in it being left in an incorrect position, reducing or eliminating its effectiveness as a drag-reducing device.

Any damage to the deflector itself should be repaired promptly.

Some deflectors have controls to enable the driver to alter the position of the deflector from the driving position. These controls must be checked periodically for proper operation.

If a vehicle with a cab roof air deflector is to be towed backwards at highway speeds, the deflector should be lowered or removed. The reverse force of the air on the deflector and shaking of the vehicle may seriously damage the cab roof, the mountings and the deflector. If the deflector is torn off it may cause a serious accident.

12.2/ Trailer and Truck Body Front Air Deflectors

These deflectors should be inspected at regular intervals for loose fastenings, fatigue cracks and physical damage, and repaired as necessary.

12.3/ COE Side Extenders

Some recent COE models are fitted with side panels extending rearward to improve rearward air flow and reduce the effect of cross winds passing between the cab and the trailer.

These panels must be inspected regularly for loose fastenings, fatigue cracks, and damage to the panels.

12.4/ Vortex Stabilizers

These are vertical panels attached to the front of van trailers to reduce turbulence and the effect of cross winds. Maintenance requirements are similar to those of cab side extenders.

12.5/ Air Intake and Exhaust Stacks

If these project beyond the sides of the cab, they should, if possible, be relocated behind the cab where their effect on aerodynamic drag will be minimized. The number of bends and elbows must be kept to the minimum to avoid increasing the restriction in the intake and exhaust systems.

12.6/ Miscellaneous

To reduce drag, any non-essential exterior accessories which interfere with the smooth flow of air over the vehicle should be removed. These

include accessories such as bug deflectors mounted above radiators, lights and grab handles, and equipment under trailers which is no longer used -- for example, spare tire carriers and propane heater tanks.

Fuel savings can also be achieved, in consultation with operations, by reassigning lower and/or smooth-sided trailers from local to line-haul service and vice versa. (This may involve switching wheels and tires so that the tires with the least rolling resistance are used in line-haul service.)

13/ SUMMARY

- Maintenance can contribute significantly to reducing vehicle fuel consumption by keeping vehicles in efficient operating condition.

- Maintenance can, moreover, in many instances increase vehicle fuel efficiency by means of modifications and special equipment.

- The degree of success achieved in contributing to fuel savings depends upon a number of factors including:

  - commitment and dedication to achieving results;

  - co-operation with drivers and the operations department in identifying and correcting causes of waste;

  - having the necessary resources (knowledge, tools, skills, parts and records) to keep vehicles in efficient condition;

  - following a preventive maintenance program which, combined with driver reports, will ensure that causes of fuel waste are corrected without delay; and

  - utilizing the specialized knowledge and services available from vehicle and component manufacturers where appropriate.